OIL

ITS CONSERVATION AND WASTE

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DEDICATION.

This book is dedicated to Mr. Daniel J. Danker, of Brookline, Massachusetts, who has given so freely of his profound knowledge of the broad aspects and conditions of the oil industry, in its preparation.

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Grateful acknowledgment is hereby made to the Bureau of Mines, the United States Geological Survey, the Oil & Gas Journal, the National Petroleum News and the Oil Weekly; and to the oil companies who have checked up some of the data contained.

CONTENTS

LIST OF TABLES

Position of the Oil Industry and Its Problems

THE OIL INDUSTRY is "the least understood and most unpopular of all the industries," as stated by F. C. Proctor, Esq., in his able treatise of October, 1927, on the Oil Problem. But it should be the most popular as it has added more—in conjunction with the motor and rubber tire industries—to the progress of the United States and the well being of its citizens during the past twenty years than all other industries combined.

That one is able to obtain in any city or hamlet in this country and in every outpost of the world, a high grade motor fuel which operates at all temperatures and under every condition and which will carry him from the Atlantic to the Pacific or around the world both over the ground or through the air, irrespective of all climatic and altitudinal conditions, the make, date, weight or size of car, bus, truck or plane or the design of motor, is due entirely to the oil industry and to the foresight, ability and progressiveness of its leaders. No specialized product is necessary for any condition of this service for the gasoline or motor spirit of any high grade oil company can be used; and the cost of this dependable and uniform fuel has never been excessive.

A million or more stockholders of oil companies and tens of millions of users of gasoline and lubricating oils are familiar with the excellent quality and low prices of the products of the oil industry. But they have had so little

actual information about its progress along scientific and other lines and the problems which it has had to overcome, that the industry has allowed itself to become the most unpopular of all. More serious still, it has laid itself open to the great mass of misinformation which is being constantly published about it and to various and varied investigations and attacks.

This ignorance of its progress and of the difficulties with which it has had to contend, is the primary cause of the industry's unpopularity. Its leaders are responsible to a certain degree for this lack of knowledge, as the old policy of secrecy is still pursued to some extent by many of the companies. However, an important change has been made during the past few years by some of them through their more complete reports to stockholders and the other information which is given out from time to time.

There have been many vital problems for the oil industry to solve during the past twenty years. Some have involved secret and competitive processes about which little or no information could be reasonably expected. But there are many facts that ought to have been given out. They would have put the industry in a more favorable light in the eyes of the public and the Federal and state governments.

Much important information would probably have been disseminated if those who dominate the companies had not been fully occupied in working out the solutions of the perplexing questions that confronted the oil industry and which were vital for the continued prosperity of this country, or if some of the leaders had not assumed that spirit of arrogance which often comes with the pride of achievement.

The present unpopularity of the oil industry is similar to that of the railroads some years ago, when they pursued their public-be-damned policy. But the popular condemnation of the railroads has been overcome to a great extent

by the better understanding of their problems and progress which has been brought about by a more general knowledge founded on published facts. Certainly, the Rails have become one of the most popular of all investments.

It is probable that the realization of the pertinent facts about the oil industry will overcome some of the resentment now felt against it and the leaders and dominating factors should give more information from time to time.

Let us consider the problems which the oil industry has had to solve during the past years and the ones which still confront it. Some of them are similar to those of other industries, but many are peculiar to the oil industry alone. Every branch, production, transportation, refining and distribution has had to overcome many obstacles in order to be able to supply the ever increasing demand for refined products at reasonable prices and to prevent, as far as possible, the waste or economic loss of our natural and national resource, petroleum.

Nature's segregation of crude oil into separate reservoirs or fields at various depths, makes its discovery exceedingly difficult and provides the first problem for oil producers. If one could be reasonably certain of striking oil in commercial quantities in any selected area, then the production branch of the industry would not be the hazardous one which it has ever been and it would be established on a sane and safe basis. This problem which has always confronted producers is well illustrated by the 75,000 or more dry holes that have been drilled during the past fifteen years at an expense in excess of $1,000,000,000. It will probably be necessary to drill several hundred thousand more before all the producing fields in the United States have been discovered.

During the drilling of wildcats and of other wells after a field has been found, oil producers have their own particular problems of possible unstable earth formations,

crooked holes, lost tools, collapsed casings, water and gas intrusion, cementing and spacing of the wells.

After wells have been brought in, the oil must be brought to the surface by natural flow, pumping, swabbing, compressed air or gas lifts or other means. Difficulties sometimes arise from paraffine accumulations and loose sand in the wells and they must be overcome. With all known methods of oil production and the prevention of well troubles, most of the oil is left in the ground. It is doubtful if over 25 to 35 per cent. of the oil content of the sands is recovered by present means.

The most important problem for producers to solve in the future is the recovery of the whole or a major part of the crude oil which cannot be won by present methods. Water flooding, the use of compressed air or gas and the restoration of gas pressures by forcing dry gas into the oil sands, have been found to be effective in certain fields. The best production method applicable to each particular field will eventually be found whereby a large percentage of the present unrecoverable oil will be obtained. The addition of certain chemicals to the water has been found to be useful in certain fields. It should become more widespread. Pure water does not free the oil film from the sand particles, while the proper chemical introduced into the waters makes such separation complete.

The fluidizing and moving powers of natural gas are becoming more and more recognized. Eventually, they will be utilized to their utmost by producers.

After crude oil has been found, difficulties have arisen in some fields for controlling the natural flow of wells under heavy pressure so that the well will not run wild and the oil be wasted in the air or on the ground. But they have been almost wholly remedied.

Then follows the evaporation losses to be overcome. This is particularly important to the oil industry as at pres-

ent constituted, as the lighter fractions of crude oil which comprise gasoline, are those which are lost through evaporation. Gasoline is the most valuable major product of crude and every particle which is wasted through evaporation decreases its recovery by that amount.

The most serious problem of producers and of our nation in respect to crude oil is the wasteful method of production—the present intensive, uneconomic and unintelligent drilling and the quick development of new oil fields. While very little crude oil is now lost, there is an important waste of the producers' own capital through the drilling of as many as five or more wells where one would have drained the present recoverable oil from the sands. A further waste is the money spent to provide the necessary steel storage for large stocks of crude oil during times of over-production; oil which should be allowed to remain in its natural reservoir, the ground.

Economically and nationally, the greatest economic loss resulting from the intensive drilling and the quick development of new oil fields, is the current depletion and exhaustion of what would otherwise become our important reserves for the coming years and future generations; and the waste of natural gas and the diminution of gas pressures which constitute the principal motive power for the natural flow of oil wells.

At least a substantial part of this depletion and exhaustion of reserves, waste of gas and dissipation of gas pressures, and unnecessary capital expenditures of oil operators for excessive drilling and the erection of steel tanks for the consequent over-production, could be prevented if producers were allowed to enter into agreements for the economic and proper development of new fields. But under existing conditions, such agreements might be construed to be in violation of our anti-trust laws and subject the producers to prosecution by Federal and state authorities.

Such modification of these laws as would permit cooperation between producers for the economic and proper development of new fields appears to be highly desirable from the national standpoint. Then oil could be produced as needed, and we would be developing additional reserves of crude petroleum. The full power of the natural gas and gas pressures could then be utilized for bringing the oil to the surface of the ground.

There is just so much crude oil contained in the sands of our oil fields. It is not being created or increased at this time. If the recoverable part of this oil is brought to the surface within a short time, then no further oil obtainable under present recoverable methods will remain in its natural reservoir under ground. While improved means, such as the introduction of gas or air into the sands, water flooding, the use of different chemicals in water for the freeing of the oil film from the sand particles, compressed air and gas lifts, the flowing of wells against back pressures and the restoration of gas pressure by forcing dry natural gas back into the sands, will eventually result in winning increased amounts of crude oil from the sands, the development and preservation of great reserves depend upon cooperation between producers. A substantial amount of recoverable oil could then be left in its natural reservoir in the new fields and our reserves augmented to that extent.

The liquid nature of petroleum forces it to flow to the nearest outlet or well, and owners of the first wells in a new field recover as much oil as possible from under their neighbors' leases. While there is some question as to the rapidity with which crude oil will percolate or flow through the sands—it depends somewhat upon its viscosity, the texture of the sands and other factors—the first wells in a field get the full benefit of the fluidizing, propelling and lifting force of the natural gas. This gas is either absorbed in the oil or stored in the upper parts of the oil sand. It is usually

held under great pressure and moves freely toward and into the nearest wells. The gas carries with it some entrained oil and forces other crude ahead of it. When wells are allowed to flow freely, gas pressures diminish rapidly until there is not sufficient force to push the oil into the wells or to provide the lifting power for the flowing of the wells.

Under present operating conditions, producers of crude oil must gain the largest amount possible of flush or first oil, both from under their own leases and the adjacent ones of other individuals and companies. The driller of a discovery well runs the financial risk of determining if oil exists in any given locality. This hazard is important, as wildcat wells often require the expenditure of over $150,000 each. If oil is found, the original developer is entitled to a substantial reward for his efforts and risk. A part of his compensation under present conditions, comes from such oil as he can win from the leases of others.

The natural drainage of crude oil into the nearest outlet or well is unavoidable owing to its liquid nature. Petroleum is not stable or fixed as are the raw materials which form the base of our iron, steel, copper, lead, zinc, coal and nearly every other industry. If crude oil were solid, there would probably be no economic loss, waste or serious overproduction problem. Producers could then recover it from the fields in such amounts and at such times as required. There would then be no possibility of its being taken out of the natural reservoir, the ground, through the nearby wells owned by others.

This unavoidable drainage of crude oil from under neighboring leases by reason of its inherent nature and the rapid flow of natural gas towards and into the first wells in a field is the cause of the large flush production of such wells. It can be prevented or equalized only by sensible cooperation between producers and owners of leases.

Under present conditions, the holders of adjacent leases

are required to drill offset wells to the discovery one as quickly as possible. Owners of other leases must drill offsets to these offsets and new offsets to the older ones until a new field has been fully exploited. All the oil which can be recovered through the natural flow is taken out of the ground within a comparatively short time and the gas pressures are reduced to a point where they are not sufficient to flow the wells. This results in the wasteful and uneconomic development of the oil fields, an unwise dissipation of the capital of producers and the depletion and exhaustion of reserves. It prevents the development of new crude oil reserves for the future use of our nation.

From the viewpoint of a fair return on one's investment, any quick and intensive development of new fields which results in the overproduction of crude oil causes a large loss to owners of settled production throughout the United States. This excess petroleum brings about lower prices of crude oil and its sale at times for less than the cost of lifting. As settled production is the backbone of the oil industry and as our nation is absolutely dependent upon it in order to supply the demands for refined products, any condition which causes a continuing loss to the owners of such production is not an enviable one from the national viewpoint, and it ought to be remedied. If continued over a period of years, it would result in the abandonment of many settled production leases and a consequent diminished supply of the raw material, petroleum. Such a result could easily become a national disaster.

Creation of Crude Oil Reserves by the Cooperative or Conservative Development of Oil Fields.

While there has been very little cooperation among producers in the development of oil fields in the United States, the conclusion that at least some of the new fields would be drilled and operated intelligently and economically, if cooperative agreements were permitted by our laws and encouraged by our Government and that excessive overproduction would be curbed to a large extent and that a large amount of crude oil would be left to remain in its natural reservoir, the ground, until needed, is not visionary, empirical or theoretical.

Five fields have been developed and operated somewhat economically and with a view to a sustained continuing production, rather than a temporary very large one. One of these fields, Big Lake, Reagan County, Texas, is controlled by two companies which decided that an intelligent and economic drilling program was more desirable than a rapid and wasteful one. The second field, Burbank, Oklahoma, was gradually developed owing to the policy of the Federal Government in restricting the various sales of Indian leases to a comparatively small part of the productive area at a time and to other cooperation between the authorities and the purchasers of leases. A third, Midway-Sunset, California, was largely controlled by a few companies. Salt Creek, Wyoming, the fourth field, is the outstanding example of cooperation between the Government and lease holders. The fifth, Ventura Avenue, California, is practically controlled by three companies who have preferred to develop their holdings in this field conservatively.

The result of the development of these five fields compared to that of certain others which were intensively drilled is shown in table 1.

TABLE 1.

RESULT OF CONSERVATIVE DEVELOPMENT OF OIL FIELDS AND THAT OF FIELDS INTENSIVELY DRILLED.

Fields Conservatively Developed.

Name	Date of Beginning of Development	Peak of Production Year	Peak of Production Barrels Daily	Production on Jan. 1, 1928
Big Lake	1923	1925	41,500	22,050
Burbank	1920	1923	122,000	37,100
Midway-Sunset	1901	1914	150,000	81,000
Salt Creek	1911	1923	160,000	42,450
Ventura Avenue	1915	1927	58,500	51,000
			532,000	233,600

Fields Intensively Drilled.

Name	Date of Beginning of Development	Peak of Production Year	Peak of Production Barrels Daily	Production on Jan. 1, 1928
Cushing	1912	1915	300,000	21,000
Breckenridge	1917	1921	135,000	7,800
Burkburnett	1918	1919	180,000	12,050
Santa Fe Springs	1920	1923	342,000	38,500
Haynesville	1921	1922	100,000	6,400
Mexia	1921	1922	194,000	8,300
Tonkawa	1921	1923	112,000	15,000
Powell	1923	1923	356,000	13,000
Wortham	1924	1925	168,000	2,200
			1,887,000	124,250

It required an average of over eight years for the first five fields to reach their peak production. New peaks by Midway-Sunset, Salt Creek and Ventura Avenue could probably be made through an intensive development. In addi-

tion to its present production, the Salt Creek field has a shut-in production of approximately 100,000 barrels a day, and Midway Sunset of 9,700 barrels. Salt Creek also contains a highly productive lower sand which has not yet been developed.

On the other hand, the peak of production for the nine intensively drilled fields was reached in less than an average of two years after the beginning of their development.

Although the mean date of the development of the first five fields was in 1916 compared to 1920 for that of the other nine fields, the current production of Big Lake, Burbank, Midway-Sunset, Salt Creek and Ventura Avenue is 1 88/100 times that of the others. If the shut-in production of Salt Creek and Midway-Sunset were opened up, the current production of these five fields would be nearly three times that of the other nine.

The total peak production of the five conservatively drilled fields was less than 2 1/3 times their current production and under 1 2/3 times their present and potential output, while the peak of the other nine fields was over 14 times their current production.

Advantages of conservative drilling and cooperation among producers for the establishment and preservation of petroleum reserves are also illustrated by the record of actual production of these fields, exclusive of the shut-in production of the Salt Creek and Midway-Sunset fields. Cushing is not included in the next table as it reached its peak of 70,000,000 barrels a year in 1915, six years before 1921, when it produced approximately 11,000,000 barrels of oil.

TABLE 2.

Approximate Production in Barrels.

Conservatively Drilled Fields.

Year	Salt Creek and Midway-Sunset 2 Fields	These Two and Burbank 3 Fields	These Three and Big Lake and Ventura Avenue 5 Fields
1921	40,900,000	47,500,000	
1922	38,900,000	73,200,000	
1923	63,500,000	95,200,000	
1924	68,300,000	98,600,000	101,100,000
1925	58,600,000	78,500,000	86,400,000
1926	51,900,000	68,200,000	94,100,000
1927	45,000,000	61,300,000	87,800,000
	347,100,000	522,500,000	

Intensively Drilled Fields.

Year	Breckenridge, Burkburnett, Haynesville and Mexia 4 Fields	These Four and Sante Fe Springs 5 Fields	These Five and Tonkawa and Powell 7 Fields	These Seven and Wortham 8 Fields
1921	57,600,000			
1922	80,900,000	91,900,000		
1923	43,500,000	123,300,000	183,700,000	
1924	31,800,000	58,200,000	114,900,000	
1925	19,400,000	38,300,000	78,300,000	94,300,000
1926	14,800,000	32,200,000	56,500,000	59,300,000
1927	13,300,000	28,400,000	42,400,000	43,550,000
	261,300,000			

	Salt Creek & Midway-Sunset	Breckenridge, Burkburnett, Haynesville and Mexia
Percentage of 1927 production:		
To that of 1921	110.1%	23.0%
To that of highest year	65.9	16.4
Decline in three years	(1924-27 34.1%)	(1922-25 76.0%)

In the year 1924, the five intensively drilled fields declined 52.8% compared with the largest decline of 20.4% in any year for the three conservatively drilled fields.

In *two* years, 1926 and 1927, the eight intensively drilled fields declined 53.8%, while the five conservatively drilled fields showed a decrease of only 13.2% in the *three* years, 1925-1927 inclusive. In 1927, the total production of the five conservatively drilled fields was over twice that of the eight intensively drilled ones, without taking into consideration the shut-in production of the Salt Creek and Midway-Sunset fields.

Salt Creek and its conservative development were the subject of comment in the September 6, 1926, report of the Federal Oil Conservation Board, as follows:

> "The Salt Creek field in Wyoming should be referred to among the larger producing fields in its freedom from uneconomic features in the program of development, a freedom due to cooperative effort in which an important factor has been the Federal supervision of operation of Government leases. At the present time, the Salt Creek field furnishes further illustration of conservative development in a program of winning the oil from the lower sands that promise best returns to both the industry and the public. The productive area of the Lakota sand, less than four miles square, includes about 20 separate leases of Federal and state lands, held by three companies but all operated by one company. Twenty-five wells have already been drilled through this sand with large initial flows, but the only production of oil from the Lakota sand has been incidental to the drilling in or subsequent short test of each well. Thirteen other wells have been drilled to the top of this sand, and the number of wells planned will be only sufficient to equalize the royalties to both owners and to private royalty interests, and it is expected

> that not more than two wells will be drilled to each 40 acres. When the area is thus drilled up and the market warrants drawing on this new supply of oil, back pressure will be maintained in the effort to obtain the maximum yield, a short test proving the material advantage of this method of conserving the gas."

Let us look at the actual results of this economic development of the Salt Creek field. Petroleum was discovered in 1908 in the First Wall Creek sand, and its producing area covers approximately 3,720 acres. But the real development did not begin until 1911. The gas pressure did not go off until 1924, or sixteen years after the discovery well was brought in and wells have flowed under their natural gas pressures for upwards of ten years. At this time, after nineteen years of development, this First Wall Creek sand is not fully exploited, as over 90% of its producing area is drilled to the extent of only one well to about fifteen acres. Within the past two years, gas pressures have been found in restricted areas which have been sufficient to flow wells at over 2,000 barrels a day. Intelligently and economically developed as it has been, very few edge, or near-edge wells, have had to be abandoned because of edge water encroachment. The First Wall Creek sand is still an important reserve of crude oil. But note: this First Wall Creek producing sand is wholly leased by three companies. It is operated by one company which has always had in mind the conservation of crude oil reserves in that district.

The next important producing horizon in the Salt Creek field is the Second Wall Creek sand, which covers approximately six times the producing area of the First Sand. This Second sand is highly competitive except as to approximately 7,700 acres owned or leased by two companies and operated by one company. The discovery well was brought in during 1917, and the sand was not subjected to an in-

tensive or economical development until 1923, and then only as the result of the sale of many leases by the Government.

Some intensive offset drilling was then necessary on that part of these 7,700 acres owned by these two companies, which was adjacent to leases owned and developed by other companies. But approximately 87% of this acreage has been developed by only one well to every twenty acres or so. As a result of this intelligent and economical development of this 87% of these 7,700 acres, important reserves of crude oil are still contained in this section of the Second sand.

Comment on the third important sand, the Lakota, is contained in the citation from the report of the Federal Oil Conservation Board. Its shut-in production is now around 100,000 barrels a day.

Underneath the Lakota sand lies another producing horizon, the Sundance sand, which has been developed by only two wells. The first one appears to be a north edge well, but the second one seems to be in the heart of the sand. The latter came in during April, 1926, and produced 6,388 barrels a day in a wide open test. It was directly east of the 3,000 barrel discovery well in the Lakota sand. This Sundance sand appears to be a non-competitive one, the leases being owned by two companies, and the operation being by only one company.

The net result of the intelligent and economic development of the Salt Creek field is a probable productive life of many years in all four major sands, the retention of most of the oil in its natural reservoir, the ground, and the creation of great reserves of crude oil.

The Federal Government is the lessor of nearly all the producing acreage in the Salt Creek field and owns important royalty interests there. Wyoming is the owner of the prolific school section in this field. As landlords or owners of royalties, it is important that the Federal and this state

Government cooperate with the producers of crude petroleum so as to prevent overproduction in the Salt Creek field and the resultant low price of crude oil. Their incomes from this source would thereby be decreased materially, and they, as well as all other owners of royalties, should receive a reasonable sum for their oil. But more important than any current income from their oil royalties is the development and preservation of large proven oil reserves.

Our Federal Government is permanently a part of the oil industry, as the owner of these and other oil producing parts of the Public Domain and of such other portions of the Public Domain as may be found to be oil producing. It is financially interested in obtaining a fair return from any future royalty oil to which it will become entitled. Certain states are also a part of the oil industry to the extent of their ownership of oil lands which are now producing or which may hereafter become productive. They are also interested through their production taxes in producers getting a fair price for their crude oil.

Superior to their respective financial interests is their duty to prevent the rapid depletion of our oil reserves and to stimulate the conservation of crude oil by producers and lease owners. As neither the United States nor the various states are the landlords of the major part of the oil producing lands of this country, they are not in a position to cooperate in the manner already in vogue in the Salt Creek field. But they can do so to the extent of permitting oil producers some freedom in entering into agreements so that future new fields can be drilled in an intelligent and economic manner; agreements which appear to be necessary only by reason of the unstable and migratory nature of the raw material and natural and national resource, crude petroleum.

The latest orgy of intensive development of new oil fields has been at Seminole, Oklahoma, where three important

and two minor ones have produced about 140,000,000 barrels of crude oil in a little over one year. This intensive Seminole development has been not only in the rapid drilling of wells but in the use of compressed air and gas to force the oil to the surface.

Although these Seminole fields produced less than one-seventh of the total crude production of the United States in 1927 and did not furnish enough crude oil to run one-sixth of the refineries which have been operating during that time, their unwise and uneconomic development has resulted in cutting in half the prices of high gravity oil and the addition to crude oil stocks east of the Rocky Mountains of over 60,000,000 barrels. They have also caused some disorganization in the oil industry.

But these items are only minor ones as the oil industry is able to stand some adverse factors. The vital result of this orgy of development in the Seminole fields is the decrease in the underground crude oil reserves of the United States by probably 100,000,000 barrels under the amount that they would have been if these fields had been cooperatively and economically developed.

Refining Problems.

THE MINOR PROBLEMS of the refining branch of the oil industry have been caused principally by the different characteristics of crude oil from the various fields. Petroleum varies from the heavy viscous crudes of around 8 degrees Baume to a very light crude of around 70 degrees. It has either a paraffine or asphalt base and contains varying amounts of impurities, principally sulphur and sulphur compounds. Usually, an important new field means another kind of crude oil for the refineries to run, with the necessary determination and solution of the most effective means for its utilization.

Pennsylvania, West Virginia, the Mid-Continent and Rocky Mountain fields furnish high gravity oil which is easy to refine. The skunk oil of Ohio which was discovered in 1885 decreased in price to 10 cents a barrel until refiners found a method for removing the objectionable sulphur compounds. Healdton, Oklahoma, gave up a dead, thick and sticky crude. The Gulf Coast, California and Mexico provide oil with a high sulphur content. Smackover gave us a heavy oil which was sold for fuel purposes without refining for some time after its discovery. Panhandle crude, with its high sulphur content, salt and excessive wax was at first considered to be usable for fuel only.

Notwithstanding the varied characteristics of the different crudes, their refining has been solved by the companies. The methods of processing the heavy Smackover and Panhandle crude have been improved to an extent where from 30 to 50% gasoline can be recovered by topping and cracking. Smackover cracked gasoline is reported to be

of a high quality and to possess such a high anti-knock value that it commands a premium. Gasoline from Panhandle crude is very stable to light and has important anti-knock qualities.

Most of the production from the recently discovered fields in West Texas is a high sulphur and very corrosive crude, which prevents its use by refineries which operate on a low sulphur high gravity oil. These West Texas crudes contain hydrogen sulphide gas, which rapidly corrodes tanks, tubes in wells, drilling lines, casing and refinery equipment. Iron sulphide is formed on the roofs of tanks. When exposed to the air, it oxidizes quickly and generates considerable heat and may cause fires.

Other impurities are contained which form hydrochloric acid when in contact with the moisture which the crude gives off, and become very corrosive. But the refineries have solved the problems connected with the refining of other sour crudes, and they will overcome those of the West Texas oils. However, as at present constituted, there are very few refineries which can handle this crude oil.

A more important problem for the refineries than the chemical and other ones which have been solved so successfully by their technical and practical men was the necessity of the continuous development of oil companies to a point where their refining capacity became equal to the ever increasing demand for refined products. Statistics of consumption are not available prior to 1916, but the development of the refining branch of the industry can be approximated from the increase in investment, cost of material, runs and other available data.

Figures for all years have not been reported and are not available, but those for the years set forth in the next tables are sufficient for us to form a proper conception of the extent of this problem.

TABLE 3.

Refinery Investment, Cost of Material and Wages Paid.

Year	Number	Investment	Cost of Material	Wages Paid
1879	86	$27,325,746	$34,999,101	$4,381,572*
1889	94	77,416,296	67,918,723	6,989,478*
1899	67	95,327,892	102,859,341	6,717,087
1904	98	131,280,541	139,387,213	9,989,367
1909	147	181,916,205	199,273,402	9,830,078
1914	176	325,646,120	325,264,509	19,397,466
1919	320	1,170,278,189	1,247,908,355	89,749,637
1921	366	.........†	1,382,170,434	102,294,108
1923	382	.........†	1,425,052,864	103,833,760
1925	359	.........†	1,889,678,019	104,645,391
1926	...	.........†	.........†	.........†

* Includes salaries.
† Not available.

TABLE 4.

Barrels of Crude Oil Refined and Selling Value of Refined Products at Refineries.

Year	Barrels of Crude Oil Refined		Selling Value of Refined Products at Refineries	
	Total	Daily	Total	Per Barrel of Crude Run
1879	17,417,455	47,719	$43,705,218	$2.58
1889	30,662,629	84,007	85,001,198	2.77
1899	52,011,005	142,496	123,929,384	2.38
1904	66,982,862	183,515	175,005,320	2.61
1909	120,775,439	330,892	236,997,659	1.96
1914	191,262,724	524,007	396,361,406	2.07
1919	365,271,803	1,000,745	1,632,532,766	4.47
1921	433,915,000	1,188,800	1,727,440,157	3.98
1923	601,747,763	1,651,365	1,793,700,087	2.98
1925	739,489,345	2,025,948	2,376,656,556	3.21
1926	779,264,000	2,134,970	Not available	
1927	828,514,000	2,269,901	Not available	

The refining industry had been operating for over thirty-five years by 1909 and was a well established one at that time. It was then confronted by a condition such as no other well established industry has had to face. This problem as shown by the results obtained was to increase within seventeen years, its investment by probably twenty times, its provision for the cost of materials and the payment of wages by about ten times and to produce refined products of a value at refineries of over tenfold.

The Standard Oil Company of December 31, 1909, one year four months and fifteen days before the United States Supreme Court ordered its dissolution, included all the Standard units of the present time. It was considered quite a large and remarkable company and pointed out as the outstanding example of the industrial development of that time. So large and important had it become that it was successfully prosecuted under the anti-trust laws as a combination in control of the oil industry.

Refining of crude oil was the main business of this Standard Oil Company and its subsidiaries. And yet, within the seventeen years since 1909, the demand for refined petroleum products has caused the upbuilding of six separate companies to a point where the refinery investment, cost of material, amount of wages paid and the selling value at the refineries of the products of *each of them* are about equal to or largely in excess of the totals of the entire refining industry of December 31, 1909. The refining business became so enormous that the Standard Oil units could not provide the necessary capital for its full development and at the same time furnish the means required by these Standard Oil units in the other branches of the industry.

While the question of providing for the great expansion of the refining industry during the past seventeen years was serious, yet it was only one of the minor difficulties which was easy to solve in comparison to the vital problem which

confronted the refining branch of the oil industry in the last and present decade; a problem not alone vital to the industry itself but one which would have retarded the progress of our country and might have resulted in an unsuccessful termination of the World War if the refining companies had not been able to work out its solution.

This main problem involved the supply of sufficient gasoline or motor fuel in order to meet the greatly increasing demand which came about through the development of motor cars, trucks and busses.

Originally, crude petroleum was refined principally for the production of kerosene or illuminating oils. The first important development of the oil companies came about because of the consumption of this refined product. Within the memory of many men in the oil industry, gasoline was only a by-product of little or no value. The demand for it was small and its riddance, rather than its sale, was the problem for the refiners. Gasoline was allowed to flow down the creeks in western Pennsylvania, along which the refineries had been built. As a certain amount of gasoline was necessarily recovered in the refining of crude oil for kerosene, this waste was a distinct economic loss. The gasoline polluted the streams and destroyed their contained life. It made the waters unfit for drinking purposes and resulted in the death of live stock, another waste.

The changing character of the demand for the various refined products is illustrated by their production since 1898, shown in Table 5. Naphtha and benzine are classified in all the tables herein as gasoline.

TABLE 5.

PRODUCTION BY REFINERIES OF THE MAJOR REFINED PRODUCTS IN BARRELS.

Year	Gasoline	Kerosene	Gas & Fuel Oil	Lubricating Oil
1899	6,685,000	29,960,000	7,257,000	4,739,000
1904	6,918,000	32,304,000	8,583,000	7,498,000
1909	12,865,000	39,876,000	40,517,000	12,793,000
1914	34,763,000	46,078,000	88,193,000	12,329,000
1919	100,134,000	54,893,000	184,950,000	19,561,000
1921	127,934,000	46,171,000	232,122,000	22,600,000
1923	186,917,000	53,307,000	285,152,000	27,396,000
1925	269,310,000	56,317,000	347,715,000	32,406,000
1926	299,734,000*	61,768,000	365,195,000	32,293,000
1927	330,667,000*	56,114,000	392,342,000	31,721,000

* The figures of production are taken frcm the report of the Bureau of Mines and are probably 7,000,000 barrels under the total refinery production of gasoline in both 1926 and 1927.

DAILY PRODUCTION BY REFINERIES OF THE MAJOR REFINED PRODUCTS IN BARRELS.

Year	Gasoline	Kerosene	Gas & Fuel Oil	Lubricating Oil
1899	18,300	82,100	19,800	13,000
1904	19,000	88,300	23,400	20,500
1909	35,200	109,300	111,000	35,000
1914	95,200	126,200	241,600	33,800
1919	274,300	150,400	506,700	53,600
1921	350,500	126,500	635,900	61,900
1923	512,000	146,000	781,200	75,100
1925	737,800	154,300	952,600	88,800
1926	821,200*	169,200	1,000,500	88,500
1927	905,900*	153,700	1,074,900	86,900

* The figures for gasoline should probably be 19,200 barrels a day more.

This increase in the production of gasoline of 810,700 barrels daily from the average 1914 output of 95,200 barrels each twenty-four hours to that of 905,900 barrels a day in 1927 was 851.6% of the 1914 output. It is an average

increase of 65.5% a year for the thirteen years, compared to an average annual increase of 1.6% for kerosene, 26.5% for gas and fuel oil and 11.4% for lubricating oils. The growth in the gasoline production is the outstanding example of any increase in the output of any product of any industry, which has been well established for over fifty years.

It is further to be noted that the percentage of increase in the production of gasoline is not based on a very small output in 1914 and that its production growth had averaged 34.1% for the five years from 1909 to 1914, and 40.1% for the ten years from 1904 to 1914. In the latter year, gasoline was one of the major products of the refining industry, as its production was 2 8/10 times that of lubricating oils, 75.4% that of kerosene, and 39.4% that of gas and fuel oil. Within the thirteen years since 1914, the gasoline output had increased to 10 3/10 times that of lubricating oils, 5 9/10 times that of kerosene, and to 84.3% that of gas and fuel oil.

This remarkable increase in the production of gasoline was caused by a similar growth in the output of motor cars, and the automobile industry was a fairly important one in 1914, as 1,711,339 cars were registered in that year.

In 1914, gasoline was the most important refinery product in values at the United States refineries and exceeded that of any other refined product, as shown in Table 6. Kerosene had been the important product up to and including 1909. In that year, its value at refineries amounted to 84.1% of the total refinery value of the other major products. It was 237.7% that of gasoline. But by 1914, the value of gasoline had increased to 51.1% of that of the other major products, while the value of kerosene had decreased to 79.4% of that of gasoline.

The figures in Table 7 show that the refinery value of kerosene in 1899 comprised 60.3% of the total value of all refinery products, while gasoline amounted to only 12.9%.

[redacted]

In 1909, their relative positions were the same, but the value of kerosene had decreased to 39.9% of the total value of refined products, while gasoline had risen to 16.8%. The important change came between 1909 and 1914 and has since continued. In 1925, the value of gasoline comprised 53.4% of the total value of refined products, kerosene only 6.8%, gas and fuel oil 20.6%, lubricating oils 10.6% and all other products 8.6%. Information since 1925 is not available.

In 1899, kerosene also commanded a higher price per gallon than gasoline, 5.9 cents, compared to 5.7 cents, as shown in Table 8. The reversal of this position had come about by 1904, when the value of gasoline was 0.6 of a cent per gallon more than that of kerosene; by 1914, the value of gasoline had increased to 8.4 cents a gallon, compared to 5.0 cents for kerosene.

The oil industry could probably have supplied the increasing demand for gasoline by a very continuous intensive development of crude oil production. If given a high enough price for crude oil, wildcatters and producers would have much greater efforts to find new fields and drill up old fields and possibly in the development of methods for an increased recovery of the oil content of the sands. But in that event, the price of crude oil would probably have increased to between $6.00 and $10.00 a barrel and the price of gasoline from 30 to 50 cents a gallon, as it would have had to bear the brunt of increased crude oil prices.

Based on the output of 95,200 barrels a day of gasoline in 1914 and the refining of 524,000 barrels of crude oil daily, the production of 905,900 barrels of gasoline each twenty-four hours in 1927 would have required the refining of 4,985,746 barrels of crude oil a day in the United States, an amount approximately 50% greater than the crude production of the entire world in 1926. On the 1924 basis of refinery output, the refining of that amount of crude oil

would have yielded 1,201,565 barrels a day of kerosene in 1927, or 1,047,865 barrels more than was actually made; 2,298,429 barrels a day of gas and fuel oil, or 1,223,529 barrels more than was produced, and 321,581 barrels a day of lubricating oils, or 234,681 barrels more than its output.

As the 1927 production of these other major products was about equal to the demand, we would then have been faced by one of two conditions: either the demand for these other major refined products would have had to be stimulated by low prices or otherwise to the total extent of around 2,506,075 barrels a day, or a part of these products would have been wasted. In either event, the result would have been a waste or economic loss of 2,506,075 barrels a day of crude oil in 1927 and very large amounts each year since 1915.

The oil industry of the United States, through the development of other means of meeting this grave problem of the increasing demand for gasoline without a corresponding increase in the demand for other refined products, can be considered as conserving today approximately 2,500,000 barrels of crude oil daily, or 912,500,000 barrels a year.

Considered from another viewpoint, the present refining of 4,985,736 barrels a day of crude by the United States refiners at this time would have required the investment of a staggering sum in order to increase the capacity of our refineries to that amount.

TABLE 6.

Value of the Major Refined Products at Refineries.

Year	Gasoline	Kerosene	Gas & Fuel Oils	Lubricating Oils
1899	$15,991,742	$74,694,297	$7,550,664	$13,351,831
1904	21,314,837	91,366,434	9,205,391	23,533,091
1909	39,771,959	94,547,010	36,462,883	38,884,236
1914	121,919,307	96,806,452	84,017,916	55,812,120
1919	766,006,055	235,663,055	318,124,339	196,242,439
1921	881,401,680	151,594,503	377,264,190	194,609,241
1923	929,900,078	146,941,897	345,666,436	204,494,849
1925	1,268,647,929	161,880,676	488,957,806	252,104,578

TABLE 7.

Value of All Products at Refineries (Including Containers), With Percentages of the Values of the Different Products to Such Total Value.

		Percentages of the value of different products to such total value				
Year	Total Value	Gasoline	Kerosene	Gas and Fuel Oils	Lubricating Oils	Others
1899	$123,929,384	12.9%	60.3%	6.1%	10.8%	9.9%
1904	175,005,320	12.2	52.2	5.3	13.4	16.9
1909	236,997,659	16.8	39.9	15.4	16.4	11.5
1914	396,361,406	30.7	24.4	21.2	14.1	9.6
1919	1,632,532,766	46.9	14.4	19.5	12.0	7.2
1921	1,727,440,157	51.0	8.8	21.3	11.3	7.6
1923	1,793,700,087	51.8	8.2	19.3	11.4	9.3
1925	2,376,656,556	53.4	6.8	20.6	10.6	8.6

TABLE 8.

Total Value at Refineries of All Refined Products per Gallon of Crude Oil Refined and Refinery Values of Different Products.

Year	Value of All Products, Per Gallon of Crude Oil Refined	Value of Refined Products Per Gallon			
		Gasoline	Kerosene	Gas and Fuel Oils	Lubricating Oils
1899	5.7c.	5.7c.	5.9c.	2.5c.	6.7c.
1904	6.2	7.3	6.7	2.5	7.5
1909	4.7	7.4	5.7	2.1	7.2
1914	4.9	8.4	5.0	2.3	10.8
1919	10.6	18.2	10.2	4.1	23.9
1921	9.1	16.4	7.8	2.9	20.5
1923	7.0	11.8	6.6	2.9	17.8
1925	7.7	11.2	6.8	3.3	18.5

Consumption and Exports of Refined Products.

THE RECORDS of the domestic consumption and exports of gasoline, kerosene, gas and fuel oil and lubricating oils are not complete prior to 1918. But as the demand for them was approximately equal to their output, the available production figures will be considered in the next table as the domestic consumption and exports.

Since 1918, the Bureau of Mines has published figures of the estimated consumption and exports of these refined products, based on the reports made by the refineries of their production and stocks on hand and on the reports of imports and exports by the Bureau of Foreign and Domestic Commerce. However, the figures of the Bureau of Mines are somewhat less than the actual domestic consumption, as all refineries have not reported to it.

TABLE 9.

DOMESTIC CONSUMPTION AND EXPORTS OF MAJOR REFINED PRODUCTS IN AVERAGE BARRELS PER DAY.

Year	Gasoline	Kerosene	Gas and Fuel Oil	Lubricating Oil	Total of Such Products
1899*	18,300	82,100	19,800	13,000	133,200
1904*	19,000	88,300	23,400	20,500	151,200
1909*	35,200	109,300	111,000	35,000	290,500
1914*	95,200	126,200	241,600	33,800	496,800
1917	181,400	110,900	433,900	49,100*	775,300
1918	240,600	126,400	469,400	54,700	891,100
1919	248,300	154,900	486,900	55,200	945,300
1920	318,200	147,300	562,000	66,400	1,093,900
1921	329,300	129,800	591,200	51,900	1,102,200
1922	388,200	153,900	703,000	64,200	1,309,300
1923	485,000	151,300	796,300	70,100	1,502,700
1924	583,000	169,900	893,000	74,200	1,720,100
1925	699,500	167,600	937,800†	83,000	1,887,900
1926	836,000	165,400	1,029,900†	‡87,600	2,118,900
1927	938,000	156,400	1,065,400†	86,100	2,245,900

* Production figures. Others are not available.

† Based on the assumption that stocks of heavy crude in California remained the same and that the increase in the stock of such heavy crude and fuel oil was entirely due to the increase in the stock of fuel oil.

‡ After deducting the California fire loss of 2,000,000 barrels of heavy crude oil and fuel oil in April, 1926.

The progressive increase in the demand for gasoline and the fluctuations in that of kerosene are better illustrated by Table 10, which shows the yearly variations in barrels per day. Gasoline has supplanted kerosene as the dominant factor in the oil industry, and the latter has become of comparatively minor importance.

Gas and fuel oil showed the largest annual increases for some years, but gasoline took away its primary position in 1923. The latter has become more solidly intrenched since then as the greatest factor in the increased consumption and exports of refined products.

Lubricants have had a fair yearly increase since 1914, except in 1927, the poor business year of 1921, and the post-war year of 1919, when large supplies were evidently in the hands of consumers. But the average annual increase in the consumption and exports of lubricating oils has been only 9.1% of that of gasoline, notwithstanding that in 1899, the production and estimated consumption and exports of such oils were 71.0% of that of gasoline. The oil industry has evidently developed a far superior quality of lubricating oils, for which it should be given credit, as their increasing consumption has been so small compared to that of gasoline and fuel oil.

Automobile registrations in 1926 were 91.1% more than those of 1921. While the consumption and exports of gasoline increased during the same period by 157.8%, yet the demand for lubricating oils increased by only 64.9%. As the consumption of both gasoline and lubes is dependent to a large extent on the use of motor cars, and the requirements for lubricating oil should keep pace somewhat with those of fuel oil, it appears that the oil industry has conserved crude oil to the extent of the greatly increased efficiency and the superior quality of the lubricating oils manufactured during the past few years.

TABLE 10.

INCREASE IN THE CONSUMPTION AND EXPORTS OF MAJOR REFINED PRODUCTS FROM YEAR TO YEAR, BASED ON THE FIGURES IN TABLE 9, IN BARRELS DAILY.

Average Per Year	Gasoline	Kerosene	Gas and Fuel Oil	Lubricating Oil	Total
1904 over 1899..	140	1,240	720	1,500	3,600
1909 over 1904..	3,240	4,200	17,520	2,900	27,860
1914 over 1909..	12,000	3,380	26,120	240*	41,260
1917 over 1914..	28,730	5,100*	64,100	5,100	92,830
Over Preceding Year					
1918	59,200	15,500	35,500	5,600	115,800
1919	7,700	28,500	17,500	500	54,200
1920	69,900	7,600*	75,100	11,200	148,600
1921	11,100	17,500*	29,200	14,500*	8,300
1922	58,900	24,100	111,800	12,300	207,100
1923	96,800	2,600*	93,300	5,900	193,400
1924	98,000	18,600	96,700	4,100	217,400
1925	116,500	2,300*	44,800	8,800	167,800
1926	136,500	2,200*	92,100	4,600	231,000
1927	102,000	9,000*	35,500	1,500*	127,000
Increase of 1927					
Over 1899 ...	919,700	74,300	1,045,600	73,100	2,112,700
Over 1914 ...	842,800	30,200	823,800	52,300	1,749,100
Increase of 1914 over 1899	76,900	44,100	221,800	20,800	363,600
Increase of 1919 over 1914	153,100	28,700	245,300	21,400	448,500
Increase of 1927 over 1919	689,700	1,500	578,500	30,900	1,300,600

* Decrease.

Before setting forth the percentages of the yearly increases and decreases in the domestic demand and export of the major refined products, the growth of the automobile

industry will be considered as the increased use of gasoline has depended upon it to a great extent. The development of internal combustion motors created a new use for the lighter hydrocarbons, gasoline, which has become paramount in recent years.

Table 11 shows the number of all motor cars registered in the United States since 1916 with the percentages of increases from year to year, together with the domestic consumption of gasoline per car registered, based on the total domestic consumption of gasoline and the total number of cars registered in the respective years. This does not mean that the average for each car was the amount shown, as gasoline is consumed for other purposes.

However, the figures are of value in showing the increasing domestic use of gasoline. Based on this method of calculation, the consumption of gasoline per car has increased by 24.9% since 1923. This growth is due partly to a larger use of motor trucks and busses which consume a much greater amount of gasoline than the average passenger car, the increasing popularity of motor touring throughout the United States, the construction of better roads, the greater all-year use of passenger cars and probably by the more comfortable riding qualities of the newer cars. A part of the 1927 increase is attributable to the decreased output of Fords.

TABLE 11.

Registration of All Motor Cars in the United States, Percentages of Increase and Average Gallons of Gasoline Consumed Per Car Registered.

Year	Registrations of All Cars	Increase in Registrations Amount	Increase in Registrations Percentage	Domestic Demand for Gasoline Per Car Registered in Gallons
1916	3,584,567			
1917	4,970,671	1,386,104	38.7%	475.8
1918	6,105,588	1,134,917	22.8	512.5
1919	7,596,503	1,490,915	24.4	452.2
1920	9,206,141	1,609,638	21.2	461.7
1921	10,505,630	1,299,489	14.1	429.9
1922	12,299,770	1,794,140	17.1	436.7
1923	15,312,658	3,012,888	24.5	429.9
1924	17,605,495	2,292,837	15.0	441.3
1925	19,857,915	2,252,420	12.8	473.5
1926	22,046,957	2,189,042	11.0	498.8
1927	23,302,668*	1,255,711	5.7	536.9

* Those for December estimated.

The percentages of increase in car registrations since 1923 have been much less than those of the increased domestic demand for gasoline, as shown in Table 12. Increases in the domestic consumption of gasoline since 1923 have become less and less dependent on the greater registrations of motor cars, due to the larger consumption of gasoline per car. The gasoline consumption figures of the Bureau of Mines are used in this table. They are somewhat less than the actual amount.

TABLE 12.

DOMESTIC CONSUMPTION OF GASOLINE, WITH PERCENTAGES OF INCREASES, COMPARED TO THOSE OF TOTAL CARS REGISTERED AND OF THE TOTAL CONSUMPTION AND EXPORTS OF GASOLINE.

Year	Domestic Consumption of Gasoline in Barrels, Bureau of Mines Figures	Percentages of Increase Over Prior Years		
		Domestic Consumption of Gasoline	Cars Registered	Consumption and Exports of Gasoline
1917	56,313,000		38.7%	
1918	74,506,000	32.3%	22.8	32.6%
1919	81,783,000	9.8	24.4	3.2
1920	101,208,000	23.8	21.2	28.2
1921	107,525,000	6.2	14.1	3.5
1922	127,906,000	19.0	17.1	17.9
1923	156,746,000	22.5	24.5	24.9
1924	185,003,000	18.0	15.0	20.2
1925	223,865,000	21.0	12.8	20.0
1926	261,813,000	16.9	11.0	19.5
1927	297,928,000	13.9	5.7	12.2

This increase in the domestic demand for gasoline in 1927 over 1926 was only 13.9%, compared to an average increase of 19.6% during the years 1923-1926 inclusive. The smaller percentage came about partly through the closing down for several months of the most important single factor in the automobile industry, the Ford plants, and by unfavorable weather conditions during a part of 1927 for the Saturday and Sunday riders.

The effect of the decrease in the production of Fords is indicated by the smaller increase of car registrations in 1927, shown in Table 11. It is more fully illustrated in the next table by the decrease in the registration of *new* Ford cars during the first eleven months of 1927 (the full year not yet being available), which was but partly offset by the increase in the registrations of *new* Chevrolets.

TABLE 13.

REGISTRATIONS OF NEW CARS FOR THE FIRST ELEVEN MONTHS.

	1926	1927	Change	
Total new passenger cars.....	3,019,803	2,515,390	504,413	Decrease
Total new commercial cars...	369,175	315,822	53,353	"
Total cars	3,388,978	2,831,212	557,766	"
New Ford passenger cars	1,073,931	388,260	685,671	"
New Ford commercial cars ...	193,471	98,552	94,919	"
Total Fords	1,267,402	486,812	780,590	"
New Chevrolet passenger cars	450,872	621,695	170,823	Increase
New Chevrolet commercial cars	52,173	100,598	48,425	"
Total Chevrolets	503,045	722,293	219,248	"
Total new Fords and Chevrolets	1,770,447	1,209,105	561,342	Net Dec.
Other new passenger cars	1,495,000	1,505,435	10,435	Increase
Other new commercial cars...	123,531	116,672	6,859	Decrease
Total other new cars ..	1,618,531	1,622,107	3,576	Net Inc.

Table 14 shows the all-important and growing position of gasoline in the oil industry and the vital problems which the oil companies have had to solve in order to meet its ever increasing demand since 1905 without producing at the same time excessive amounts of other refined products. The latter would have resulted in a very large economic loss or waste of crude petroleum.

TABLE 14.

PERCENTAGES OF INCREASES IN CONSUMPTION AND EXPORTS OF MAJOR REFINED PRODUCTS OVER PRECEDING YEARS.

Year Average Per Year	Gasoline	Kerosene	Gas and Fuel Oil	Lubricating Oil	Total
1900-1904	0.8%	1.5%	3.6%	11.5%	2.7%
1905-1909	17.0	4.8	74.9	14.1	18.4
1910-1914	34.1	3.1	23.5	0.7*	14.2
1915-1917	30.2	4.0*	26.5	15.1	18.7
Over Preceding Year					
1918	32.6	14.0	8.2	11.4	14.9
1919	3.2	22.5	3.7	0.9	6.1
1920	28.2	4.9*	15.4	20.3	15.7
1921	3.5	11.9*	5.2	21.8*	0.8
1922	17.9	18.6	18.9	23.7	18.8
1923	24.9	1.7*	13.3	9.2	14.8
1924	20.2	12.3	12.1	5.8	14.5
1925	20.0	1.4*	5.0	11.8	9.8
1926	19.5	1.3*	9.8	5.5	12.2
1927	12.2	5.4*	3.4	1.7*	6.0
Of 1927					
over 1899	5,025.7	90.2	5,380.8	562.3	1,586.1
over 1914	885.3	23.9	341.0	154.7	352.1
1914 over 1899...	420.2	53.7	1,120.2	160.0	272.9
1919 over 1914					
War period	160.8	22.7	101.5	63.3	90.3
1927 over 1919					
Post-war period.	277.8	1.0	118.8	57.8	137.6

* Decrease.

The principal method for supplying these important increases in the domestic consumption and exports of all major refined products was the development of a larger production of crude oil. That was the only way in which it was accomplished prior to 1915. Crude oil production in the United States was increased from an average of 156,-358 barrels a day in 1899 to 728,116 barrels daily in 1914, or

by 365.7%, compared to the increase of 272.9% in the domestic consumption and exports of the major refined products.

This 1914 production of 728,116 barrels a day was 231,316 barrels a day more than the total refinery output of these major refined products. Of this excess, 27,207 barrels had been run through the refineries and is accounted for by the output of other refinery products and the losses sustained in refining operations. Approximately 138,800 barrels a day of the remaining crude was consumed as fuel oil without being refined and the rest of the production was added to crude oil stocks, less evaporation, pipe line and other losses and the export of an average of 8,137 barrels a day.

Production in the United States continued to increase, and it averaged approximately 2,460,000 barrels a day in 1927. That shows an increase of 1,475.2% over the 1899 production and is somewhat less than the increase of 1,586.1% in the domestic consumption and exports of the major refined products.

However, while this increased crude oil production was more than enough to provide kerosene, gas and fuel oil for the national needs and for export, it could not have met the much greater demand for gasoline, if it had been refined by the methods existing in 1914. In that year, the total gasoline recovery of the United States was equal to only 18.2% of the amount of crude oil refined, and it had varied between 10.4 and 12.8% in 1899 to 1909. While this 18.2% recovery in 1914 showed either a substantial improvement in the refinery methods of producing gasoline or an adjustment of refinery products to the increasing demand for gasoline since 1899, the refining art as practiced in 1914 could not have provided the necessary gasoline for the subsequent years from the crude oil produced in those years. For on the 1914 basis of the recovery of gasoline from crude oil of somewhat under 18.2%,

as a part of its production was attributed to cracking and to natural gasoline, it would have been necessary to have refined over 5,153,800 barrels a day of crude oil in 1927 in order to provide the 938,000 barrels a day of gasoline which was consumed in the United States and exported during that period.

Table 15 shows the amount of crude oil per day which it would have been necessary to refine since 1916 in order to provide for the United States consumption and exports of gasoline, based on the 18.2% recovery of 1914. It is rather surprising to find that such requirements of crude oil by the United States refineries alone since 1923, would have been considerably more than the entire world's production of crude; that during 1927, they would have been twice the actual production of the United States and 50% greater than the entire world's production in 1926.

TABLE 15.

Barrels of Crude Oil a Day Which it Would Have Been Necessary to Produce and Refine in Order to Have Provided the Gasoline Consumed in the United States and Exported, Based on the 18.2% Gasoline Production to Crude Oil in 1914, Compared With the Crude Production of United States and the World.

Year	Barrels of Crude Oil Required Per Day	Average Daily Production of Crude Oil — United States	World
1917	996,700	918,700	1,377,500
1918	1,321,900	975,100	1,379,000
1919	1,364,300	1,036,600	1,552,600
1920	1,748,400	1,210,200	1,902,200
1921	1,809,300	1,293,700	2,098,700
1922	2,133,300	1,527,500	2,352,700
1923	2,664,800	1,957,000	2,783,000
1924	3,202,200	1,950,700	2,769,500
1925	3,843,400	2,092,400	2,928,100
1926	4,593,400	2,112,000	3,002,600
1927	5,153,800	2,460,000	3,417,000

But even the crude oil requirement in 1927 of twice the production of the United States and at least one and one-half times that of the whole world which would have been necessary in order to supply the gasoline demand—if the oil industry had not further increased the efficiency of its refineries since 1914, saved a considerable part of the former evaporation losses, developed the natural or casinghead gasoline industry and succeeded in transforming gas and fuel oil, the heavier fractions of crude oil, into the lighter fractions, gasoline, through pressure or cracking stills—does not present the full picture of the problem which confronted the industry in 1914.

The production of natural gasoline had begun prior to 1910 and 2,800 barrels a day were produced in 1914. A part of this natural gasoline was used in the refineries and included in their reported output of gasoline for that year, but the exact amount is not available. Furthermore, the cracking of gas oil and distillate had begun in 1912 and the refineries produced approximately 5,600 barrels of cracked gasoline a day in 1914. By deducting these amounts of natural and cracked gasoline utilized or produced by the refineries in that year from their total gasoline output of 95,200 barrels a day, it is found that the refineries recovered only 86,800 barrels a day of gasoline out of the 524,000 barrels of crude oil run, or 17.1%.

Refining of Crude Oil.

THE REFINING of crude oil today and as it was practiced in 1914, is done in three ways, all of them at atmospheric pressure; through skimming or topping, steam refined and asphalt plants. Complete refining consists of the separation of the various contents of crude oil by distillation into gasoline, kerosene, reduced crude, gas oil, paraffine distillate, cylinder stock, wax, asphalt and coke.

Crude oil contains probably several thousand different constituents which are difficult to separate completely and to identify with certainty. They can, however, be divided into certain types or groups through distillation. These groups overlap each other to some extent, the heavier fractions of the lighter ones being the lighter fractions of the heavier groups.

The lightest fractions of crude oil vaporize at below ordinary atmospheric temperatures and other light fractions up to 437 degrees Fahrenheit. This group represents the gasoline of commerce and contains that part of the crude oil which comprises the evaporation losses when exposed to the air. The heaviest components of commercial gasoline in 1915 vaporized at 370 degrees F. but the present specifications require that the vaporization or end point be not more than 437 degrees F. However, not less than 90% of the gasolene must vaporize below 383 degrees and some companies manufacture a product that contains no fractions vaporizing at over 400 degrees F.

Owing to the fact that gasoline became more valuable than kerosene between 1899 and 1904 and has since held this advantage and in order to meet the greatly increasing de-

mand, the refiners began to put into gasoline some of the heavier portions of the light products which had formerly constituted the lighter parts of kerosene. A considerable amount of these fractions vaporized at between 300 and 400 degrees and constituted the heavy naptha ends. They therefore became a part of commercial gasoline, instead of being used in the production of kerosene.

This heavy naptha is neither gasoline nor kerosene but may become a part of either, according to their respective demand. All of it cannot be put into gasoline as there are not enough lighter products to equalize all the heavy naptha produced. Without such compensation, gasoline would thereby become an unsatisfactory motor fuel. A certain amount of these heavy naptha fractions are required for finished kerosene in order to make it easy to ignite and to prevent its becoming too heavy and viscous.

In order to use this heavy naptha in gasoline, it must be mixed with a larger quantity of lighter products. For its utilization in kerosene, it must be offset by a larger amount of heavier fractions.

For satisfactory operation in motors, gasoline must not contain too large a percentage of either the very light ends or the heavy ones. A gasoline composed of very light fractions would be entirely too volatile and has not the power of a properly blended product. If it contains too many heavy components, it would not possess the proper vaporization quality.

The change in the specifications for commercial gasoline is shown in Table 16 and came about through the necessity of using a larger percentage of the heavier ends. It has resulted in the production of a product of proper volatility and power.

TABLE 16.

SPECIFICATIONS FOR COMMERCIAL GASOLINE.

Year	Limit of Heat at Which 20% Must Vaporize	Ditto 50%	Ditto 90%	Ditto 100%
1915	180 degrees F.	225°	310°	370°
1925	195 degrees F.	266°	383°	437°

Kerosene comprises the next group of the constituents of crude oil. Its fractions begin to vaporize at around 350 degrees F. and up to 575 degrees or a little over.

Gas oils comprise the third group and their lightest fractions vaporize at or a little below 450 degrees F. while the heaviest ones evaporate at or somewhat beyond 750 degrees.

Subsidiary series in this third group are the paraffine distillates, cylinder stocks and waxes. Asphalt and coke remain after these other groups are taken off.

In skimming or topping plants, a certain amount of crude oil is treated at one time. The still is then cleaned out and another charge of petroleum is put in. Gasoline is boiled off first and then the kerosene. These vapors pass through pipes into the condensers and are liquefied into gasoline and kerosene. Sometimes steam is introduced in order to agitate the crude and to bring about distillations at lower temperatures. The bottoms consisting of reduced crude are then drawn off. While the operation of the older skimming plants is not continuous, many of the modern ones are operated continuously through a series of several stills. Pipe stills which also permit of continuous operation have been introduced during recent years and are a considerable improvement over the others. The products of a skimming plant are gasoline, kerosene and reduced crude. The latter is usually sold as a fuel oil.

In refineries which run for steam refined products, the first part of the operation is the same as in skimming plants

and the gasoline and kerosene are recovered. The bottoms which remain are then treated with additions of increasing quantities of steam in order to produce primary gas oil and paraffine distillate. The remaining heavy oil is cylinder stock which is removed from the still and diluted with a large quantity of naptha. It is then filtered through Fuller's earth and reduced to low temperatures in order to freeze the contained wax, which settles in large cold tanks. The remaining oil is then drawn off from these settling tanks and is redistilled to take off the naptha. The residuum forms a cylinder oil. If asphalt is present in the crude, the process is modified by its removal from the bottoms by means of sulphuric acid, as it would ruin the lubricants. The products of these stills are gasoline, kerosene, light and heavy lubricating oils and wax.

Coking refineries follow the process of steam distilled ones except that no steam is used. After the gasoline and kerosene are taken out, a cut of primary gas oil is made as in steam refining, but a higher temperature is necessary because of the absence of steam. Then follows the paraffine distillate, the slop cut and still wax. The residue is coke.

Conservation of Crude Oil.

THERE is just so much gasoline in crude oil but it varies according to its grade. Some crudes contain a very small percentage of gasoline while others have over 30%. But no more of the lighter fractions which constitute gasoline can be obtained from crude oil by refining than are contained in the original petroleum.

Prior to 1912, it became apparent to the leaders of the oil industry that any improvements that could be made in refining processes and apparatus and in the prevention of evaporation losses, would not provide sufficient gasoline to meet the increasing demands; and that a large amount of gasoline must therefore be recovered from natural gas or the heavier products of crude oil must be converted or cracked into the lighter fractions. Cracking had been done to a certain extent in the production of kerosene but it could be accomplished only to a very slight extent by refineries operating at atmospheric pressure.

After many experiments and the expenditure of a large amount of money the conversion of these heavier particles into lighter ones or the gasoline fractions was finally effected through the use of increased temperatures at much higher pressures. Cracking has become the outstanding factor in supplementing the production of gasoline, in order that the ever increasing demand could be met at a reasonable price.

Upon four things, then, depended the production of sufficient gasoline to supply our national and the international needs:

Increased refinery efficiency;

Prevention or reduction of the former evaporation losses of the light fractions of crude oil, comprising gasoline;

Additional production of natural or casinghead gasoline, and

Cracking.

In cracking lies the glory of the oil industry, the supreme achievement. It will ever be a classic to which all other industries may aspire. It puts to blush the dream of the old alchemists, the discovery of the philosopher's stone. For we have in cracking, not the transmutation of a base metal into gold which could be of very little economic value if produced in large quantities—it would thereby result in debasing that precious metal and destroy our financial structure—but a worthwhile transformation, the transmutation of a low cost and abundant non-volatile fluid into the highest known element of crude oil, gasoline, a product which has become so essential for the outstanding and predominating position of this country.

In Table 17 is set forth the number of additional barrels of crude oil which it would have been necessary to refine under the 1914 conditions, in order to have produced the amount of gasoline represented by its increased percentage of production through refinery improvements and the reduction of former evaporation losses, by cracking processes and by natural gasoline plants. Some criticism of the amount of crude oil shown under "Through increased efficiency and reduction of evaporation losses" may be made as the change in the specifications for commercial gasoline undoubtedly resulted in a somewhat higher percentage of gasoline recovery from crude, at the expense of the kerosene output.

It is assumed for the purpose of showing the conservation effected that the prevention of the necessity of refining these additional barrels of crude oil by reason of the production of gasoline in the ways shown, has resulted in the *conservation* of crude petroleum to that extent.

The importance of the conservation shown in Tables 17 and 18 is difficult to comprehend from the figures alone. But when it is realized that during the last 12 years the conservation effected in the United States has been greater than its entire crude production up to 1921; that it was over 62% of the entire world's production up to that year; that such conservation alone was 54% more than the total crude oil production of the United States in 1922-1926 inclusive and 8% more than the world's production for that period; and that nearly one-half of this conservation has been effected within the past three years, not only the importance of the progress of the oil industry during the past few years, but its absolute necessity, becomes apparent.

TABLE 17.

Conservation of Crude Oil Effected Through the Increased Efficiency of Refineries and Reduction of Evaporation Losses, the Cracking Processes and the Production of Natural Gasoline, Based on the 1914 Refinery Recovery of 17.1% of Gasoline from Crude Oil, in Barrels.

Year	Through Increased Refinery Efficiency and Reduction of Evaporation Losses	Through the Cracking Processes	Through the Recovery of Natural Gasoline from Natural Gas
1916	....	40,600,000	14,400,000
1917	24,200,000	57,100,000	30,300,000
1918	87,800,000	68,900,000	39,300,000
1919	81,700,000	90,600,000	49,000,000
1920	133,000,000	94,400,000	53,600,000
1921	135,200,000	124,300,000	62,700,000
1922	193,000,000	148,400,000	70,400,000
1923	262,600,000	165,700,000	113,600,000
1924	316,300,000	200,900,000	130,000,000
1925	247,000,000	401,100,000	157,000,000
1926	295,600,000	548,200,000	189,800,000
1927	321,800,000	592,000,000	226,100,000
Total	2,098,200,000	2,532,200,000	1,136,200,000

Table 18 shows the total barrels of crude oil conserved and the average barrels per day with the ratios to the total production of the United States and the world. So impressive are these figures that it is exceedingly difficult to realize what the oil industry has done in conserving our national and natural resource, petroleum.

But the effect of the progress made by the oil industry in its efforts to supply the gasoline demand has been more far-reaching than the conservation of crude oil, for the success which has attended these efforts has kept down the prices of refined products below what they should be nor-

mally. The very efficiency of the industry has had an important adverse reaction against it in the matter of prices.

The Federal Government through the Bureau of Labor and Department of Commerce publishes the retail prices of certain commodities and its bulletins are available to every one who takes the trouble to inquire for them. Of all the commodities listed, gasoline is the lowest priced and shows the least increase since 1913, notwithstanding the increased cost of the production of the raw material, petroleum, and of its refining.

There has been quite a lot of agitation about the low prices of farm commodities but their average prices for the first nine months of 1927 were 55% more than those of 1913 while the average retail prices of gasoline for the same period showed an increase of only 12.2%. The average retail prices of all listed commodities, including household goods, building material, cloths and clothing and farm products for the first nine months of 1927 was 46% over those of 1913 and this average was somewhat less than it otherwise would have been if it had not included gasoline which had increased by only 12.2%. The average prices of all these commodities, including gasoline, since 1913 has been 56% over those of 1913, compared to 20% for gasoline.

[redacted]

TABLE 18.

TOTAL CONSERVATION OF CRUDE OIL THROUGH THE INCREASED EFFICIENCY OF REFINERIES AND REDUCTION OF EVAPORATION LOSSES, CRACKING AND THE PRODUCTION OF NATURAL GASOLINE, BASED ON THE 1914 REFINERY RECOVERY OF 17.1% OF GASOLINE FROM CRUDE OIL, COMPARED TO THE UNITED STATES AND THE WORLD PRODUCTION OF CRUDE OIL.

Year	Total Barrels	Daily Average	Percentage to Crude Production United States	Percentage to Crude Production World
1916	55,000,000	150,300	18.3%	11.9%
1917	111,600,000	305,700	33.3	22.2
1918	196,000,000	537,000	55.1	38.9
1919	221,300,000	606,300	58.5	39.8
1920	281,000,000	767,800	63.4	40.0
1921	322,200,000	882,700	68.2	42.1
1922	411,800,000	1,128,200	73.9	48.0
1923	541,900,000	1,484,700	75.9	53.3
1924	647,200,000	1,768,300	90.6	63.9
1925	805,100,000	2,205,000	105.4	75.3
1926	1,033,600,000	2,831,800	134.1	94.3
1927	1,139,900,000	3,123,000	126.9	91.4
	5,766,600,000	1,315,700	85.8	58.9

In discussing the conservation of crude oil, the point may well be taken that it is unfair to base the amount of the conservation effected through cracking and the production of natural gasoline from natural gas, upon the percentage of the recovery of gasoline by refining in 1914; especially as refinery improvements, the reduction of evaporation losses and the change in the specifications for commercial gasoline since then have increased the percentage of gasoline recovery from crude oil very materially, as shown in Table 17.

If cracking and natural gasoline plants had not been developed, then the amount of additional crude which would

have had to be produced and refined in any year in order to meet the then current demand for gasoline, may very properly be based on the percentage of gasoline recovered from crude oil by refineries during that year.

Working on this basis due credit for the conservation of additional amounts of crude oil should be given to the progress made in the art of refining and to the decrease of evaporation losses effected by the oil industry. For the fact remains that if evaporation losses had not been reduced and if there had not been any improvements made in the art and apparatus of refining since 1914, the percentage of gasoline recovery from crude oil since would be approximately that of 1914, subject to the comparatively small amount of the lighter fractions of kerosene which have since been put into commercial gasoline.

Giving this credit to the important developments by the oil industry in decreasing evaporation losses and in installing refinery improvements, then the conservation of crude oil through cracking and the recovery of natural gasoline would be as shown in Table 19.

TABLE 19.

CONSERVATION OF CRUDE OIL THROUGH CRACKING AND NATURAL GASOLINE PLANTS, BASED ON THE PERCENTAGE OF THE REFINERY RECOVERY OF GASOLINE FROM CRUDE OIL DURING THE RESPECTIVE YEARS.

Year	% of Gasoline Recovered from Crude by Refining	Additional Barrels of Crude Oil Necessary to Have Been Refined in Order to Have Produced the Gasoline Made by		
		Cracking	Natural Gasoline Plants	Total for Both
1914	17.1%	11,861,000	5,941,000	17,802,000
1915	17.1*	24,228,000	9,099,000	33,327,000
1916	17.0	40,865,000	15,082,000	55,947,000
1917	18.4	53,505,000	28,196,000	81,701,000
1918	21.7	54,323,000	31,000,000	85,323,000
1919	21.0	73,743,000	39,857,000	113,600,000
1920	22.3	72,408,000	41,081,000	113,489,000
1921	22.3	95,305,000	48,040,000	143,345,000
1922	23.7	107,080,000	50,819,000	157,899,000
1923	24.8	114,276,000	78,363,000	192,639,000
1924	25.5	134,738,000	87,192,000	221,930,000
1925	22.8	292,031,000	117,741,000	409,772,000
1926	23.6	397,187,000	137,521,000	534,708,000
1927	23.8	425,311,000	162,478,000	587,789,000
Total		1,896,861,000	852,410,000	2,749,271,000

* Estimated.

The increasing ratio of gasoline recovery in the United States by refineries since 1916 and up to 1925, as shown in the preceding table, reflects the improvements in refinery construction and practice and the prevention of former evaporation losses. Percentage decreases since 1924 came about through the refining of a greater amount of heavy oil, which contains a comparatively small amount of gasoline.

This running of heavy oil through the refineries has become more and more important and not much unrefined crude is now used for fuel purposes, compared to that of some years ago. The refining companies are endeavoring to

extract the gasoline contained in all crude oil, and this necessitates the running of heavy oil which was not done some years ago.

Daily averages are more illustrative of the conditions as we have been taught to think in barrels of production per day. So they are set forth in Table 20, together with the percentages to the crude production of the United States and of the world.

TABLE 20.

CONSERVATION OF CRUDE OIL THROUGH CRACKING AND NATURAL GASOLINE PRODUCTION, BASED ON THE PERCENTAGE OF THE REFINERY RECOVERY OF GASOLINE FROM CRUDE OIL IN THE YEARS SHOWN; AND CRUDE OIL CONSUMED BY REFINERIES WITH THE TOTAL CRUDE NECESSARY TO PRODUCE STRAIGHT RUN GASOLINE EQUAL TO THE TOTAL AMOUNT PRODUCED, ETC. ALL IN BARRELS DAILY.

Year	Crude Oil Consumed by Refineries	Additional Crude Necessary to Produce Straight Run Gasoline Equal to that Produced by Cracking and Natural Gasoline Plants	Total Crude Consumed Plus that so Conserved	% of Total to the Total Crude Production of U. S.	% of Total to the Total Crude Production of World
1914	524,000	48,800	572,800	78.7%	52.4%
1915	528,400*	91,000	619,400	80.4	52.9
1916	674,800	152,400	827,200	100.7	65.7
1917	863,400	223,900	1,087,300	118.3	79.0
1918	893,200	233,800	1,127,000	115.6	81.7
1919	990,500	311,200	1,301,700	125.6	85.5
1920	1,185,600	310,100	1,495,700	123.6	78.6
1921	1,214,700	392,700	1,607,400	124.2	76.6
1922	1,371,800	432,600	1,804,400	118.1	76.7
1923	1,592,400	527,800	2,120,200	108.3	76.2
1924	1,758,700	606,400	2,365,100	121.2	85.4
1925	2,027,200	1,122,700	3,149,900	150.5	107.6
1926	2,135,000	1,464,900	3,599,900	170.4	119.9
1927	2,279,100	1,610,400	3,889,500	158.1	113.8

* Estimated.

Main Problems of the Industry Restated.

ON THE BASIS of the actual achievements of the oil industry since 1916, at a time when it was one of the best established of all industries in the United States, its problems over a period of the eleven years since, have been as follows:

To increase the production of crude oil in the United States from an average of 821,770 barrels a day in 1916 to 2,460,000 barrels daily in 1927, or by 199.4%. That did not mean merely the drilling of the 192,493 new producing oil wells during that period at the old average depths of less than 2,000 feet, but it required boring many of the new wells to between 4,000 and 7,000 feet. Producing wells during the past few years have cost up to $150,000 each, and a conservative estimate of the average cost of the new oil producing wells drilled since 1916 would be around $15,000. On that basis, the total cost of the new oil wells brought in since 1916 would amount to $2,887,395,000. But that is not all that the producing branch of the oil industry had to contend with since 1916, as approximately 66,774 dry holes were drilled during these years. The cost of a dry hole may exceed $125,000, and a conservative estimate of the average cost of these dry holes would be $10,000. At that price, the dry hole cost to oil producers during the past eleven years amounted to $667,740,000;

To increase the production of natural gas from an average of 2,066,000,000 cubic feet a day in 1916 to over 4,132,000,000 cubic feet daily in 1927, or by 100.0%. That involved the drilling of 24,458 gas wells during that period at an estimated cost of not less than $200,000,000;

To increase the capacity of its refineries from a point where they averaged runs of 674,800 barrels of crude oil a day in 1916 to an average of 2,279,000 barrels daily in 1927, or by 237.7%. This was not done through the simple construction of so many additional skimming plants or refineries of the 1916 type, but it involved the scrapping of most of the old equipment, the converting of many of the old skimming plants into complete refineries, and the building of a large number of complete refineries and additions to the older ones;

To prevent or reduce evaporation losses and to increase the capacity and efficiency of its refineries to where they produced an average of 540,500 barrels of straight run gasoline a day in 1927, compared to an average of 115,000 barrels a day in 1916, an increase of 370.0%; and so that the gasoline recovery by present refinery methods, exclusive of cracking, could be increased to 25.5% of the crude oil processed in 1924, compared with 17.0% in 1916, an increase of 50.0%. The decrease to 22.8% in 1925, to 23.6% in 1926, and to 23.8% in 1927 was due to the much larger amount of heavy oil run; heavy oil which contains only a small percentage of gasoline;

To increase the capacity of its cracking plants from a point where they averaged only 19,000 barrels a day of cracked gasoline in 1916 to where they could and did average 277,300 barrels daily in 1927, or by 1,359.6%. This was not done by the mere construction of many additional units of the 1916 type, but it required the erection of many improved batteries of the old style, the development of new and more efficient processes and the building of a large number of units of the new types;

To increase its natural gasoline plants from a capacity where their output averaged 6,732 barrels a day of natural gasoline in 1916 to where they could and did produce 105,900 barrels daily in 1927, or by 1,473.1%. This growth did

not come about by the installation of additional units similar to those of 1916, but through the replacement of much of the equipment of the old plants, the development of a new and improved process of manufacture, and the installation of this more efficient type;

To increase its pipe line facilities from an average collection and delivery of approximately 800,000 barrels a day in 1916 to an average of around 2,400,000 barrels daily in 1927, or by 200.0%;

To increase its domestic distribution and marketing of the major refined products from around 570,000 barrels a day in 1916 to an average of approximately 1,914,000 barrels daily in 1927, or by 235.8%;

To increase its storage capacity where it could take care of the 220,000,000 barrels or so of stocks of all liquid petroleum and products in 1916 to one carrying approximately 584,184,000 barrels on December 31, 1927, or by 165.5%. This percentage of the increase in stocks is less than the other percentages of increases shown herein;

To increase its tankers and other facilities for export business so that they could deliver an average of 375,000 barrels a day in 1927, compared to 170,000 barrels daily in 1916, an increase of 120.6%;

To increase its tankers and other facilities for domestic business so as to provide water transportation for an average of 782,000 barrels a day of crude oil and refined products from California, Texas and foreign countries to the East Coast refineries and ports in 1927, compared to 128,000 barrels a day in 1916, an increase of 510.9%.

Surplus Profits of Oil Companies.

This enormous development of the oil industry required the further investment of additional billions of dollars. Fortunately for our national prosperity and progress, the major oil companies during the decades preceding 1916 had built up gigantic surpluses which were the mainstay of the oil industry during this subsequent period of necessary expansion and which became of vital importance in meeting the grave problems as they arose.

These large surpluses had been created at the expense of stockholders, as dividend payments had been very small. They probably averaged less than 4% on the investment. That is entirely too little a return on capital put into an industry which involves all the financial risks of the oil business, unless there were undistributed net earnings which went into building up substantial surpluses. A fair consideration of the surpluses shows that they are not the property of corporations in the most important sense, but that they belong to hundreds of thousands of small and large stockholders who have not received the entire net income to which they were entitled or which their investment earned.

These hundreds of thousands of small and large investors, many of them being the employees of oil companies, are practically partners in the oil business. Corporations, in the ultimate analysis, are only a combination of many stockholders. They are soulless because no method has yet been devised by legislation or otherwise, whereby the various states can endow their own creations with something that they do not possess themselves. Yet corporations

represent the aggregate soul of their stockholders and employees, the same as our states and the Federal Government comprise the incorporeal part of their citizens.

The great surpluses of the oil companies consist of a myriad of small sums which belong to the individual stockholders. It is through the foresight and wisdom of the governing bodies, the directors and officers of intelligently and properly conducted corporations, that these many small sums were not distributed to their real owners, the stockholders, but were held together in order to meet the exigencies and vicissitudes of business which may arise, and which did come to confront the oil industry during the past decade.

While the total amount of surpluses, cash and securities on hand and investment in capital and other assets of the corporations engaged in the oil business as of December 31, 1916, is not available, the approximate figures for 13 major companies were as follows:

TABLE 21.

Surpluses	$800,000,000
Investment in capital assets, after many millions of dollars deducted for depreciation and depletion	570,000,000
Cash and securities	100,000,000
Current and other assets	650,000,000
	$1,320,000,000

It was well for the future of the industry in view of the call which was to be made upon it during the next ten years that it had been able to accumulate these surpluses and assets of December 31, 1916. While cash and marketable securities were not large comparatively, yet in view of the billions which it has been necessary to invest in the industry since then, the fact that through able and con-

servative management these oil companies had retained the larger part of their net income in the form of accumulated surpluses was the outstanding factor for the attraction of further huge investments into the industry, investments which were absolutely necessary in order to meet the subsequent constantly increasing demand for its expansion.

As illustrative of this enormous expansion that became necessary, the approximate amount of surpluses, cash and securities, investment in capital assets and current and other assets of these 13 companies on December 31, 1926, were as follows:

TABLE 22.

Surpluses	$1,435,000,000
Investment in capital assets, after hundreds of millions of dollars deducted for depreciation and depletion	2,073,000,000
Cash and securities	411,000,000
Current and other assets	1,981,000,000
Total	$4,465,000,000

A comparatively small part of some of these items came through consolidations and increase in the book value of plants.

It has become increasingly apparent that the salvation of the oil industry has been in the hands of its major units, and this takes in all of its branches. As present partners with the Federal Government in the development of the lands of the Public Domain already under lease, the full cooperation between them has worked out for the benefit of both. In order to prove up other probable oil bearing parts of the Public Domain, companies with the proper financial resources and ability for careful and able develop-

ment should be encouraged to undertake this task by being allowed to acquire leases to worth while acreages.

The expense of the discovery of new fields today is so large that these companies with vast resources and proven ability are in the best position to undertake it.

Cracking Processes.

As shown in Table 17, the gasoline produced by cracking in 1916-1927 inclusive has been equal to the straight-run gasoline which would have been recovered through the refining of 2,532,200,000 barrels of crude oil at the 1914 rate of gasoline recovered by the refineries. That barrelage is 33.7% of the United States production of petroleum, and 23.0% of that of the entire world in those years.

On the basis of the percentage of gasoline recovery from crude oil by refining during the respective years, the cracked gasoline output has been equal to the amount of straight run gasoline which would have been produced from 1,896,-861,000 barrels of petroleum in 1914-1927 inclusive, as shown in Table 19. That barrelage is equal to 28.2% of the United States crude production and to 19.4% of that of the world during that period.

The importance of cracking has been constantly increasing. In 1927, it conserved 425,311,000 barrels of crude, which is equal to 47.3% of the United States production, based on the refinery recovery of gasoline from crude oil during that year.

Not only has cracking conserved these large amounts of crude oil which it would have been otherwise necessary to produce and refine in order to meet the demand for gasoline, but it has saved the entire oil situation through the elimination of the necessity of producing and refining a further huge amount of crude oil and in preventing the production of vast quantities of additional fuel oil, kerosene and lubricating oils which would have been thrown on the market or wasted if these additional barrels of crude oil had been refined.

Cracking has become the outstanding factor in the conservation of crude oil since 1924. The approximate production of cracked gasoline is shown in the next table.

TABLE 23.

APPROXIMATE PRODUCTION OF CRACKED GASOLINE IN BARRELS, WITH PERCENTAGES OF YEARLY INCREASES OVER PRECEDING YEAR.

Year	Barrels of Cracked Gasoline Produced: Total	Barrels of Cracked Gasoline Produced: Daily Average	Percentage of Yearly Increase
1913	1,552,000	4,300	....
1914	2,028,000	5,600	30.2%
1915	4,143,000	11,400	103.6
1916	6,947,000	19,000	66.7
1917	9,845,000	27,000	42.1
1918	11,788,000	32,300	19.6
1919	15,486,000	42,400	31.3
1920	16,147,000	44,100	4.0
1921	21,253,000	58,200	32.0
1922	25,378,000	69,500	19.4
1923	28,340,000	77,600	11.7
1924	34,358,000	93,900	21.0
1925	68,583,000	187,900	100.1
1926	93,736,000	256,800	36.7
1927	101,224,000	277,300	8.0
	440,808,000		

What are these cracking processes which take the heavier fractions or parts of crude oil and convert most of them into the more desirable and useful lighter fractions, gasoline?

A number of processes are covered by the term "cracking." Considerable heat under substantial pressure is used, which may operate in one of a number of ways:

The molecules of the heavier fractions of crude oil may be separated and then allowed to reunite into the particles composing the lighter fractions;

Or the molecules themselves may be disintegrated into their component atoms which may recombine into a different type of molecule, that of the gasoline series;

Or one or more atoms of each molecule of the heavier fractions may be permanently removed, which may result in the formation of a molecule having different characteristics;

Or one or more of the disintegrated atoms may join the atoms which form the molecule of the heavier fractions, and thus make the molecule of gasoline.

Atoms which would be left over under the last three theories may combine to form the non-condensible gases, gum-forming constituents or coke, which are also the result of cracking.

The exact nature of the reactions which occur during cracking operations is not known. It will probably turn out to be very simple when fully understood. But up to date, physicists and chemists have not advanced to a point in their determinations where they can be sure of what takes place during the cracking process. The art also appears very complex. There is plenty of room for the further study of its nature and of some improvements in its practice.

However, one thing is certain. An inferior product is transmuted or converted into a superior one in respect to their present utility, demand, and value. The only thing which appears to be thoroughly understood about these cracking processes is that the work required of them is done satisfactorily both commercially and otherwise.

Cracking would not be possible were it not for the progress made in the steel industry in the development of its products to a point where they will stand heavy pressures at high temperatures. So we find that progress in one art is dependent on that made in others. In oil refining as formerly carried on, the necessary heat required caused

considerable danger when pressures of 75 pounds to the square inch were used. But the steel since developed and now used will stand a pressure up to 1,000 pounds under high temperatures with far less danger than that which formerly attended pressures of 75 pounds.

Given the necessary heat and pressure, the construction of apparatus of sufficient strength and which will allow these reactions to occur at the proper place and sufficient time for them to be completed, we have a commercial cracking process.

There are two main systems of commercial cracking, bulk pressure and tube stills.

Bulk pressure cracking is comparatively slow. A large body of the heavier fractions of crude oil comprising the cracking stock is held for a number of hours at the necessary cracking temperatures of 700 degrees Fahrenheit or upwards and under pressures ranging from 95 pounds to the square inch or over. All the different fractions of the cracking stock which range from a vaporization point of around 450 degrees Fahrenheit and above evidently do not require the same length of time for their cracking to be completed as the vapors which contain or comprise the cracked gasoline come off continuously. The partly unchanged cracking stock remains for a longer time under heat and pressure in order that its cracking may be completed.

Pressure is necessary as it permits the application of much higher temperatures to the cracking stock and still keep it liquid. Pressure also prevents the premature cracking of the lighter fractions and accelerates the rate of cracking of the entire mass.

In tube cracking, the stock to be cracked is forced under pressure through long narrow tubes which are heated to a high temperature. Near and at their outlets, they are usually at a bright red heat. As the stream of oil flows

through these tubes, some of it disintegrates and passes off in the form of vapor. This vaporization is gradual. Both the liquids and the vapors and the cracked and uncracked material go along together into the reaction tanks, where some of the cracking takes place, and they are subjected to cracking for the same length of time. In some types of tube cracking, practically all the oil is vaporized before it enters these reaction chambers.

Tube cracking is completed much quicker than that by the bulk process, probably because of the higher degrees of heat used, of from 850 degrees Fahrenheit and upwards. Pressures are used of from 350 to over 750 pounds to the square inch and only a short time is necessary for the completion of the cracking.

The Burton Cracking Process.

Approximately 947,219,000 barrels of crude oil have been conserved through the use of the Burton cracking process up to January 1, 1928, as about 212,210,000 barrels of gasoline have been made by these units. Based on the percentage of gasoline recovered by the refining of crude oil during the respective years that this process has been in operation, that barrelage of gasoline is equal to the amount which would have been recovered from 947,219,000 barrels of crude. That is equal to 12.6% of the total crude production of the United States in 1913-1927 inclusive, during which this process has been in commercial operation.

Standard Oil of Indiana is entitled to all the credit for this important conservation of crude oil as it developed the Burton processs, which was the first commercial cracking one. The Company began experiments along this line in 1908 or 1909 and had spent over $1,000,000 in development work before the first commercial Burton unit was completed in the latter part of 1912.

The distillate from the first Burton stills was off color and somewhat unpleasant in odor. The Company endeavored to market it as a "motor spirit" at a price considerably under that prevailing for gasoline but afterwards decided to distill out the gasoline.

It was found that the gasoline production from crude oil could be about doubled through the use of Burton stills in connection with the refining of oil. Patents were granted to Standard of Indiana in 1913 and 1914, under which the Company had a practical monopoly of all cracked gasoline until 1921, as the Burton process was the only commercial one in operation up to that year.

It was a matter of grave consideration by its directors as to whether this monopoly would be retained by the Company on account of its important position as a marketer of gasoline, or if licenses would be granted to others for the use of this Burton process. In 1914, permission was given to others for its use under royalty or other agreements, and licenses have since been granted to the following companies:

Standard Oil of New Jersey
Standard Oil of Kansas
Standard Oil of New York
Standard Oil of Ohio
Standard Oil of Kentucky
Standard Oil of Louisiana
Standard Oil of California
Humble Oil & Refining
Magnolia Petroleum
Utah Refining
Tide Water Oil Company
Tidal Refining Company
Galena Signal
Lion Oil & Refining
Solar Refining
Aetna Refining Company
White Eagle Oil Company
Petroleum Refining Company

The Burton cracking process is a bulk pressure one and operates in single units. The still or shell is 8 feet in diameter and about 30 feet long and holds a charge of 196 barrels. It is built so that the fire strikes the lower half of the still only. The upper part projects above the supporting walls and is insulated in order to prevent the escape of the contained heat. Two large vapor pipes are inserted in the upper part of the still and provide a passageway for the

vapors to ascend into an air cooled partial condenser where they are chilled. The heaviest part of these vapors comprise the material which has not been cracked sufficiently. It liquefies under this air cooling and falls back through this same vapor line into the still.

Uncondensed vapors which comprise the lighter or gasoline fractions pass to the final water cooled condenser from which the resultant condensate and gases go into the receiving drum. There, the gas separates from the liquid and passes off into the high pressure line. It carries the gas from a number of stills and is under a pressure of around 95 pounds to the square inch. Through this common connection with the high pressure line, all of these stills operate under the same pressure and through one control.

The liquid distillate passes out of the bottom of the receiving drum and is afterwards redistilled for its gasoline content, which is about 60% of the total volume.

In the still itself, carbon is deposited during the cracking operation. This carbon or coke is one of the necessary evils which attends cracking operations. In the early Burton stills, it accumulated on the bottoms and occasionally caused hot spots, which resulted in more or less injury to the still shells.

After the charging stock has been cracked and distilled, the resultant pressure tar is drawn off and the fires extinguished. Carbon and the products of corrosion formed during the operation are scraped from the inside of the still and removed. Steam is then introduced in order to displace the air and gas mixture so that fires and explosions will not occur when the fresh charging stock is introduced.

This charging stock consists of fresh or virgin gas oil, paraffin light ends, which are the lighter fractions of paraffin distillate, naptha bottoms, which comprise the residue from the distillation of the cracked distillate of prior runs, and cycle stock, which consists of the lighter fractions dis-

tilled from the pressure tar produced in these cracking stills.

After the fresh stock has been put in, the first step is to drive off the water originally contained in the charging stock and which is also formed from the condensation of the steam. This water and a very small amount of very light fractions of the crude oil are distilled off at atmospheric pressure and pass through the vapor line and condensers into the receiving drum, where it is taken out. This step requires from three to five hours.

When the water is wholly drawn off, the charging stock is heated to about 400 degrees Fahrenheit, and gas from the high pressure line is allowed to flow into the still until the pressure is raised to 20 pounds. This stops the further distillation of the stock at this temperature. In some plants, the full vapor line pressure of 95 pounds is used.

The pressure of 20 pounds is then gradually increased to 95 pounds and the temperature of the charged stock raised from 400 to around 750 degrees Fahrenheit. This pressure increases the distilling temperature of the charged stock. If the increase of pressure were omitted, the charge would distill at the applied temperature and it would not be cracked. But through this pressure of around 95 pounds, the charge is held in the still under cracking conditions, and the gasoline distillate of the desired composition comes off at a fairly constant rate.

Distillation proceeds as follows: When the pressure becomes 95 pounds and the cracking temperature of the charge is reached, the control valve connecting the receiving drum with the high pressure vapor line is gradually opened and distillation of the charging stock begins. From 3 to 4% of the stock is taken off per hour, and complete distillation requires from 12 to 15 hours. The resultant distillate contains about 60% gasoline.

Approximately 55% of the whole charge is distilled.

While it can be continued until a larger amount has been vaporized, the result is a much larger deposit of carbon or coke with consequent hot bottoms.

During the distillation of the first 25% of the charged stock, there is practically no carbon deposit. Between 25 and 35%, the deposition of coke is slow. It becomes serious after 55% is vaporized. Practically as much carbon is formed between the 55 and 60% points as has been produced in the total run to 55%. Up to that point, about 1/10th of 1% of the charged stock has been converted into coke.

The cracked distillate is then refined. Pressure tar which has been withdrawn from the still through a cooling system is also distilled and the distillates comprise the cycle stock which becomes a part of the new charge.

These Burton stills are limited in their production of cracked gasoline on account of their not being capable of a more or less continuous operation, the comparatively small charge which can be treated at a time and the serious coke formation after 55% of the charged stock has been cracked and vaporized. They possess no mechanical means for throwing down the coke, and it must be removed by manual labor after the fires are drawn. The Humphreys false bottom, which constitutes an improvement on these stills, are a part of each one and collect some of the coke which would otherwise be deposited on the bottoms of the stills. Their use results in quicker and easier cleaning and safer operation.

A substantial improvement was made by Standard of Indiana on the basic Burton process through its development of tube stills and bubble towers. Instead of applying heat to the bottoms of the stills, it is directed against a bank of tubes situated in the fire box. The still itself is mounted above these tubes and connected with them and is entirely protected from the fire and insulated to retain the heat.

In these Burton tube stills, the charged stock circulates rapidly through the tubes and the still.

The tube stills are larger than the Burton shell ones already described, and they have a charging capacity of 310 barrels each. While it was found to be impractical to add fresh charging stock to the shell stills during operation, an additional 167 barrels are fed into the tube stills. It replaces the stock which has been distilled off. So that the entire charge of the tube stills is 477 barrels during one operation, compared to 196 barrels for the original Burton shell ones. They can handle over twice the amount of the Burton shells during one cycle and are therefore more efficient than the original type Burtons.

Bubble towers, which take the place of the air cooled condensers of the first Burtons, consist of vertical towers divided by a series of horizontal plates, on which separate pools of liquid collect. Each plate has an overflow pipe which extends downwards nearly to the top of the next plate. This pipe is sealed by the liquid contained on the plate. This liquid is largely composed of that part of the charging stock which has been previously vaporized but not fully cracked. It drops from one plate to another until it reaches the bottom of the bubble tower and is then returned to the cracking stills.

In order that the uncondensed vapors comprising the cracked gasoline fractions may ascend to the top of the bubble tower from which they pass into the water cooled condensers, a series of short pipes are inserted in the plates. These pipes are open at the bottom and surmounted on top by caps or bells which extend below the liquid level. As the uncondensed vapor rises from one plate to another, it goes through these tubes into the space under the caps, then below their edges into and through the liquid in a series of bubbles. The contained heat is partly absorbed by the liquid oil and the heavier or uncracked part of the vapors

condensed, while the gasoline fractions pass on to the final condenser.

The advantages of the Burton process are the formation of a high grade cracked gasoline which contains a certain amount of anti-knock compounds—the unsaturated hydrocarbons—and a comparatively small loss of material through the production of non-condensible gases during its operation. Its disadvantages are that it cannot be run continuously, as very frequent shut-downs are necessary for cleaning and inspection; that it does not produce over 35% of gasoline from the charging stock, and that very little of the once-run stock can be recycled through the stills.

However, there has been a substantial improvement in the process since it was developed. This is shown by the increase in efficiency, as approximately 40% more gasoline from the charging stock is now recovered than was produced in 1914.

Standard Oil of Indiana itself has developed a continuous cracking process which produces a much higher percentage of gasoline from the charging stock and has installed a number of units at its refineries. But the Burton process must be given the credit for conserving the greatest amount of crude oil effected by cracking.

The gasoline produced by the Burtons is shown in Table 24, in which the figures for 1913-1919 inclusive are approximately correct, those for 1920-1924 inclusive are calculated from available data, and the ones for 1925, 1926 and 1927 are estimated from reliable information. The latter may be slightly over or under the actual production.

TABLE 24.

PRODUCTION OF BURTON CRACKED GASOLINE IN THE UNITED STATES WITH PERCENTAGES TO THE TOTAL PRODUCTION; AND THE RESULTANT CONSERVATION OF CRUDE OIL BASED ON THE PERCENTAGE OF GASOLINE RECOVERY THROUGH STRAIGHT REFINING IN THE RESPECTIVE YEARS.

Year	Barrels of Burton Cracked Gasoline Produced	% of Total Production of Cracked Gasoline	Barrels of Crude Oil Conserved	% to Total Crude Production of United States
1913	1,552,000	100.0%	9,132,000*	3.7%
1914	2,028,000	100.0	11,861,000	4.5
1915	4,143,000	100.0	24,288,000*	8.6
1916	6,947,000	100.0	40,865,000	13.6
1917	9,845,000	100.0	53,505,000	15.9
1918	11,788,000	100.0	54,323,000	15.3
1919	15,486,000	100.0	73,743,000	19.0
1920	15,645,000	96.9	70,157,000	15.8
1921	20,042,000	94.3	89,874,000	18.8
1922	22,687,000	89.4	95,727,000	17.2
1923	21,677,000	76.5	87,407,000	11.9
1924	21,970,000	64.0	86,157,000	12.1
1925	22,100,000	32.2	96,930,000	12.7
1926	20,500,000	21.9	86,864,000	11.3
1927	15,800,000	15.6	66,386,000	7.4
	212,210,000		947,219,000	

* Based on the estimated percentage of refinery recovery of gasoline from crude oil.

Based on the 1914 rate of refinery recovery of gasoline from crude oil of 17.1%, the gasoline produced through the Burton process in 1913-1927 inclusive was equal to the amount of gasoline which could have been recovered from 1,241,000,000 barrels of crude, or 17.8% of the United States production of petroleum in that period.

The record of the Burton process is one of noble effort, the result of the great foresight of a Standard Oil, backed by practically unlimited technical and financial resources.

It was a necessary supplement of our sources of gasoline at a time when it was required for the continued progress of this country and when the supply of cracked gasoline was of vital importance during the World War.

Approximately 48.1% of the cracked gasoline produced in the United States has been made through the Burton process. It has further worked for the conservation of crude through the units installed in foreign countries.

The Burtons will continue to be important producers of cracked gasoline for some years to come. But their relative importance will decline. Other types of cracking stills will replace them as they wear out and are scrapped. The oil industry has been among the foremost of all to scrap apparatus involving a large investment, when newer and better processes and apparatus have been developed, which either increase the conservation of crude oil or reduce the cost of operation.

The development of the Burton process involved problems of the design and construction of stills and equipment so that they would stand the very high temperatures at which steel as then made, began to lose its tensile strength. The stills also had to be built so that they would withstand pressures in excess of 100 pounds to the square inch at these high temperatures. With the present day knowledge and experience, this is a simple matter. But for the first few years, it was one of the most serious problems in the development of the cracking art.

It is to the credit of the Standard Oil Company (Indiana) that it built hundreds of Burton stills and operated them for over eight years and produced millions of barrels of gasoline through them before a fatal accident occurred.

The Holmes Manley Cracking Process.

THE TEXAS COMPANY was the second one to develop a commercial cracking process. It was one of the early pioneers in this branch of the industry and had begun research and development work in 1910 or 1911. Over $500,000 had been expended by 1918, when it began the construction of its first commercial unit. Before it was completed and put into commercial operation in February, 1920, a further sum of $819,000 had been used. This Company has spent in the neighborhood of $16,000,000 for installing Holmes Manley plants in its refineries, and this does not include the cost of steam plants, power plants, water supply and tankage used in connection with the process.

In 1914, it acquired an option on the Joseph H. Adams pending patents and contracted to purchase them in 1919. Mr. Adams had been working to develop a cracking process and apparatus since 1907 or 1908 along somewhat similar lines to those of The Texas Company and had applied for a patent on December 1, 1909. Some of the features contained in his patents are embodied in the Holmes Manley process.

The Holmes Manley cracking unit consists of a furnace which contains a coil of pipe for the heating of the cracking charge. The upper part of this coil is located in a heat economizer which utilizes the high temperature of the flue gases, and the lower part is in direct contact with the furnace fire. This coil is extended to the first and second of a series of four vertical stills in which the oil is cracked. No heat is applied to the bottoms of these cracking stills, but they are lightly fired on the sides well above the bottoms and below the level of the oil so as to prevent any substantial amount of carbon deposition and danger from hot spots.

Each still contains a revolving scraper which continually operates during the cracking procedure and throws down the heavy petroleum particles and accumulating coke to the bottom of the stills. A pipe connects the stills in series through which vapors and liquid pass. The vapor line is attached near the top of the last still to carry the vapor into the bottom of the bubble tower. A tube at the top of this tower then passes through a condenser and into the receiving drum. From the bottom of the bubble tower, a pipe leads to the heating coil for the return of the stock which has not been sufficiently cracked so that it may be recycled through the stills. Outlets are provided at the bottom of each still in order to draw off the pressure tar.

This Holmes Manley apparatus utilizes the high temperature of the vapors and distillates as the primary source of heat for the fresh charging stock. At the same time, this cold stock helps to condense the vapors.

In the operation of this process, the cold fresh charging stock, which is substantially the same as that used in the Burton stills or it may be crude oil, is forced at a pressure of about 350 pounds through a pipe in the condenser box, where it absorbs heat from the hot vapors and gasoline and itself acts as a cooling or condensing agent. The charge then goes through a coil in the upper part of the bubble tower and absorbs more heat, which would otherwise be wasted. By this time, it has attained a temperature of from 450 to 500 degrees Fahrenheit without the use of any primary heat, and it then enters the heat economizer, where it absorbs more heat. As the oil leaves this section, it meets and commingles with the hot recycle stock coming from the bubble tower. Both form the new charging stock in the proportion of about 60% of fresh stock to 40% of recycle stock.

This cracking stock then enters the lower part of the heating coil, where it receives the heat from the fires of the

furnace. By this time, the pressure has dropped to about 300 pounds on account of the frictional resistance of the tubes, and the temperature is raised to around 800 degrees Fahrenheit.

The heated oil then passes into the bottom of the first cracking still under a pressure of 250 pounds or more, although some of it may be fed into the bottom of the second cracking still. The gentle heat applied against the sides of these cracking stills keeps the oil at a cracking temperature.

As the vapors are formed in these stills, they pass with some of the oil through the vapor line from still to still and then out into the bottom of the bubble tower, where all the vapors are cooled. Those consisting of the uncracked part of the charge condense and become the recycle stock of the process. The lighter vapor comprising the cracked gasoline is then forced through coils in the condenser box and liquefy into gasoline.

The scrapers are continuously revolving against the sides of the stills and remove the heavy petroleum particles which would otherwise become coke. These particles form a part of the pressure still tar which is drawn off at the bottom and sold for fuel oil. Through the use of these scrapers, the process can be operated continuously for as long as five months at a time.

A unit of the Holmes Manley has a through-put of about 1,700 barrels of charging stock a day and converts up to 75 or 80% of it into gasoline under certain conditions. It produces normally from 60 to 70% gasoline. The coke formed in the stills, working and storage tanks is less than one-half of one per cent of the charge.

The Holmes Manley process is recognized as the highest embodiment of the art of bulk pressure cracking. It can be operated so as to produce only gasoline, pressure tar which is sold for fuel oil, a small percentage of coke and a

comparatively small amount of non-condensible gases. The oil is passed through the heating coils at a velocity which results in very slight cracking in them and, therefore, the formation of very little coke.

Varying amounts of gasoline and fuel oil can be produced through proper regulation, according to the respective demand and prices of these refined products. The gasoline from some of the units can be made so that it does not have to be redistilled or treated with sulphuric acid, but it is finished with the doctor treatment.

The Holmes Manley process has the advantage of all bulk pressure systems in the rapid removal of gasoline from the cracking zone practically as soon as it is formed, thus preventing its recracking which causes a considerably larger loss from non-condensible gases.

In addition to its advantages of a very large daily throughput of charging stock and the high percentage of gasoline recovery, these stills are a very decided improvement over other bulk pressure ones inasmuch as they utilize the heat units of the hot vapors and liquids which would otherwise be wasted; are capable of continuous operation from one to five months; have comparatively low operating costs and fewer repairs, and permit of the continuous rerunning of the recycle stock. The removal of pressure tar as formed results in a cleaner cycle stock than can be obtained by other stills of this type.

But all these results were not accomplished in a day or a year. The throughput of the original 24 units of the Holmes Manley process, which were completed in 1920 at the Port Arthur plant of The Texas Company, averaged 577 barrels a day of charging stock in 1921, the first year of full operation. It had increased to an average of 694 barrels a day in 1922. Recent units have a daily throughput as high as 1,750 barrels.

It is interesting to note the increased efficiency of these stills in regard to gasoline recovery. The daily average of the Holmes Manley stills of The Texas Company in barrels a day is shown in the next table.

TABLE 25.

DAILY AVERAGE THROUGHPUT, ETC., OF THE HOLMES MANLEY STILLS OF THE TEXAS COMPANY IN BARRELS.

	1921	1922		1925	1926
		1st 6 mo.	2nd 6 mo.		
Charging stock used	13,862	17,854	18,573	38,464	38,810*
Gasoline produced	3,291	4,637	5,600	22,567	23,286
Per cent. of gasoline to charging stock	23.7%	26.0%	30.2%	58.7%	60.0%*

* Estimated.

The gasoline yield of the three units at its Tulsa plant which began operation in July, 1922, was 28.8% of the charged stock for that year, and the yield of the Lockport stills which began operation in September, 1922, was 35.9% in that year, compared to the recoveries of 23.7% in 1921, and of 27.9% in 1922 at the Port Arthur plant.

Licenses for the use of this process have been granted to the following companies which have installed units at their refineries:

White Eagle Oil & Refining
Lincoln Oil Refining
Crown Central
Utah Oil Refining
Cities Service
California Petroleum

Standard of Indiana has also completed a number of modified Holmes Manley units at its various refineries.

The total production of cracked gasoline by means of the Holmes Manley process is shown in the next table.

TABLE 26.

Production of Cracked Gasoline by the Holmes Manley Process in Barrels, With Percentages to the Total Production of the United States and the Resultant Conservation of Crude Oil, Based on the Percentage of Gasoline Recovered from Crude Oil Through Straight Refining in the Respective Years.

Year	Barrels of Holmes Manley Cracked Gasoline Produced	% to Total Cracked Gasoline Made in United States	Barrels of Crude Oil Conserved
1920	501,971	3.1%	2,251,000
1921	1,184,351	5.6	5,311,000
1922	1,783,643	7.0	7,526,000
1923	3,798,600	13.4	15,317,000
1924	7,839,640	22.8	30,704,000
1925	10,282,330	14.9	45,098,000
1926	11,755,450	12.5	49,811,000
1927	14,058,030	13.9	59,067,000
Total	51,204,015		215,085,000

The Holmes Manley cracking stills of The Texas Company and its licensees now have a rated capacity of over 190,000 barrels of charging stock a day. They should produce more than 20,000,000 barrels of cracked gasoline during 1928. That would result in the conservation of over 84,000,000 barrels of crude oil, based on the percentage of straight run gasoline refined from crude oil in 1927. It is equal to approximately 230,000 barrels of crude a day, or 9.5% of the average daily production in the United States in 1927.

The Tube and Tank Cracking Process.

THIS PROCESS is a tube cracking one, and it has been developed by Standard Oil of New Jersey. This Company was one of the earliest licensees of the Burton process from Standard of Indiana. It had installed the Burton stills as early as 1915 and spent considerable money in trying to increase the production of gasoline per still.

In 1918, Standard of New Jersey began work on a process for the cracking the very heavy Mexican Panuco oil in order to reduce its viscosity and make it easier to handle. The experiments led to the Company's development of the Tube and Tank cracking process. In January, 1921, it acquired the Carleton Ellis patents which covered some features of the Tube and Tank stills. The commercial operation of these stills began in that year.

The apparatus consists of a coil of pipe or tubes for the heating of the charging stock, which is connected with a vertical reaction tank called the soaker or digester; a pipe runs from the top of this digester into the separator chamber, which comprises the lower part of the bubble tower; from the top of the bubble tower, a pipe leads to the main condenser, where the cracked gasoline becomes liquefied and then passes into the receiving drum. Another pipe leads from the lower part of the bubble tower to carry the uncracked oil or cycle stock back into the system. From the bottom of the separator chamber, the pressure tar is withdrawn through a proper outlet.

Fresh charging stock under a pressure of about 400 pounds is forced through a coil in the top of the bubble tower where it absorbs heat from the hot vapors, heat which would otherwise be wasted. It then passes through the

heating or cracking coil where the pressure drops to about 350 pounds through frictional resistance and the temperature of the oil is raised to about 850 degrees F. This high temperature cracks a considerable amount of the oil in the heating coil. It is raised as nearly as possible to the degree of heat where it would cause too much coke to be formed which would necessitate too frequent cleanings. Approximately ten per cent. of the charging stock is converted into gasoline vapor in the heating coil. The hot vapors and oil then pass into the reaction chamber or digester where the principal part of the cracking takes place and the coke is formed. As no heat is applied to this digester, the coke deposited is harmless and cannot result in hot spots. The temperature falls to about 785 degrees F. which is sufficient for vigorous cracking. Control over the rate of cracking and the formation of coke is maintained by forcing cold cracking stock into the bottom of the digester when necessary.

As this digester is kept almost full of oil at all times, the vapors and some oil pass out through a relief valve in the pipe at the top of this digester and into the separator chamber at the bottom of the bubble tower. Upon passing this valve, the pressure drops to about 60 pounds and the temperature to around 700 degrees, the latter being caused by the increased evaporation which takes place through the reduction of the pressure.

The heavy liquid, pressure tar which is used as fuel oil, falls to the bottom of the separator and is withdrawn practically as fast as formed. Rising through the bubble tower, the heavier parts of the vapor condense and the liquid drops to the bottom where it is taken off as cycle stock and reprocessed again through the system. The lighter vapors which contain the gasoline fractions pass upwards through the bubble tower and out of the pipe at the top into the condenser where they liquefy. They then flow with the

non-condensible gases into the receiving drum. These two products then separate out under a pressure of 50 pounds.

Units of the Tube and Tank cracking process have a charging capacity of from 1,000 to 2,000 barrels a day. Their efficiency to a production at this time of 75% and upwards of gasoline from the charging stock is a great improvement over the 14.2% recovered in 1921, which has taken years to develop. The percentage of actual recovery depends on the grade of charging stock and the kind of products desired. Panuco crude does not yield as large an amount of gasoline as domestic fuel oil, gas oil or high gravity crudes. The process is very flexible and the amount of gasoline made depends to a great extent on the demand and price of fuel oil.

The production figures given below are approximately accurate.

TABLE 27.

BARRELS OF CRACKED GASOLINE PRODUCED BY THE TUBE AND TANK PROCESS IN THE UNITED STATES, WITH PERCENTAGES TO ITS TOTAL PRODUCTION AND THE RESULTANT CONSERVATION OF CRUDE OIL BASED ON THE GASOLINE RECOVERED FROM CRUDE OIL THROUGH REFINING IN THE RESPECTIVE YEARS.

Year	Barrels of Tube and Tank Gasoline Produced	% of Total Cracked Gasoline Made	Barrels of Crude Oil Conserved	% to Total Crude Production of United States
1921	23,600	0.1%	106,000	0.02%
1922	178,000	0.7	751,000	.13
1923	778,000	2.7	3,137,000	.43
1924	1,950,000	5.7	7,647,000	1.07
1925	3,830,000	5.6	16,798,000	2.2
1926	14,200,000	15.1	60,169,000	7.8
1927	19,700,000	19.5	82,773,000	9.2
	40,659,000		171,381,000	

Tube and Tank cracking stills have been installed also by Humble Oil & Refining, Standard Oil of Louisiana, Beacon Oil, Louisiana Refining Company, Tide Water Oil, Standard Oil of Ohio, Vacuum Oil and Galena Signal. The present charging capacity of all Tube and Tank cracking units in the United States is over 200,000 barrels a day. Their production in 1928 should be in excess of 30,000,000 barrels of cracked gasoline. That means the conservation of more than 126,000,000 barrels of crude oil, based on the refinery recovery of gasoline from crude oil in 1927, or at the rate of 345,000 barrels a day.

The vital importance of these three cracking processes, the Burton, Holmes Manley and Tube and Tank, in helping to conserve the crude oil resources of the United States can be further illustrated by the fact that the production of cracked gasoline by Standard Oil of Indiana, The Texas Company and Standard Oil of New Jersey and its subsidiaries, Standard of Louisiana and Humble Oil & Refining, is approximately equal to 100% of their total production of gasoline through refining. That is nearly twice the ratio of the total production of cracked gasoline to straight run by all companies in the United States, including these five major ones, which was only 51.3% in 1927.

It must also be borne in mind that some of the other companies use one or more of these three cracking processes. The total contribution to the conservation of crude oil in the United States in 1928 by the Burton, Holmes Manley and Tube and Tank cracking processes should be considerably more than 250,000,000 barrels, or over 683,000 barrels a day, based on the 1927 percentage of gasoline recovered from crude oil by refineries. That is equal to 27.8% of the average daily production of United States crude oil in 1927.

The Cross Cracking Process.

THIS PROCESS is also a tube cracking one. It was perfected by Doctors Roy and Walter Cross who had worked on its development long prior to 1918. Commercial units were first put in operation in 1921. Very high pressures and temperatures are used which is in line with the progress in the art of destructive distillation.

The apparatus consists of a heating or cracking coil for the direct application of the heat and a heavily insulated horizontal tank, called the reaction or digestor chamber, to which no heat is applied. Connection is made from one end of this digestor to a vertical second tank, or separator. From the top of the separator, a pipe leads to the bubble tower which contains a condensing chamber near the bottom. From the top of the bubble tower, another pipe leads into the condensing coil and then into the receiving drum. At the bottom of the separator is an outlet through which the pressure tar, formed during the operation, is drawn off. A pipe is located at the bottom of the bubble tower through which a fraction similar to gas oil is withdrawn. It constitutes the cycle stock which is retreated through the system.

Fresh charging stock is fed under a pressure of about 750 pounds through the coil in the upper part of the bubble tower where it absorbs heat from the hot vapors. It then passes into the heating or cracking coil. On account of the frictional resistance, the pressure drops to about 700 pounds. The temperature is raised in the heating coil to the cracking one of approximately 850 degrees F. and the high pressures used cause a very rapid circulation of the oil. It then passes into the reaction tank or digestor where the oil is allowed

to remain for an appreciable time for cracking to take place and a substantial amount of gasoline vapors to be formed, as well as the pressure tar. This digestor is kept partly full of liquid products and the temperature falls to some extent, but not enough to stop the cracking. A mixture of liquid products and vapor then pass into the separator tank which is operated at a reduced pressure.

All of the products go off as vapors except the heavy pressure tar. It falls to the bottom and is withdrawn and the vapors pass into the bubble tower. Their heavier fractions are there condensed into cycle stock, which is withdrawn and reput into circulation through the cracking system. Gasoline vapors and the non-condensible gases flow from the top of the bubble tower into and through the coil in the condenser, from which the resultant gasoline and gases pass into the receiving drum.

This Cross cracking process is owned by Gasoline Products Company, Inc., which does not own or operate any plants or refineries. Its business consists of the development of a cracking method, the ownership of patents and the issuance of licenses to refiners for the operation of this process.

Licenses have been granted to the following companies who have installed one or more units of the Cross Cracking Process:

TABLE 28.

Licensees of the Cross Cracking Process.

Sapulpa Refining Company, taken over by Continental Oil Co.
Waite Phillips Company, now Barnsdall Refineries, Inc.
Clayton Oil & Refining, now owned by Simms Petroleum Company.

Indian Refining Company.	Magnolia Petroleum Company.
Globe Oil & Refining Co.	Texas Pacific Coal & Oil. Co.
Petroleum Refining Co.	Atlantic Refining Co.
Pure Oil Co.	Pierce Petroleum Corporation.
Roxana Petroleum Co.	Richfield Oil Co.
Solar Refining Co.	Betrin Petroleum Co., a subsidiary of the Barber Asphalt Co.
Union Oil Co. of California.	Marland Oil Co.
Barnsdall Refining Co.	Vacuum Oil Co.
Sun Oil Co.	Standard Oil of New York.
Miller Petroleum Corporation.	Champlin Refining Co.
Waverly Oil Works Co.	American Refining Co.
Skelly Oil Co.	

The information set forth in the next table may be a little under the actual figures, but it is approximately correct.

TABLE 29.

Cross Cracking Stills; Charging Capacity, Barrels of Cracked Gasoline Produced Through Them in the United States, With Percentages to the Total Production and the Resultant Conservation of Crude Oil, Based on the Gasoline Recovered from Crude Through Refining in the Respective Years.

Charging Capacity on	Barrels Per Day
Dec. 31, 1921	600
" " 1922	6,600
" " 1923	14,800
" " 1924	45,200
" " 1925	88,200
" " 1926	159,200
" " 1927	183,200

Year	Barrels of Cross Cracked Gasoline Produced	% of Total U. S. Cracked Gasoline Produced	Barrels of Crude Oil Conserved	% of Total Crude Production in United States
1921	2,750	0.01%	12,000	neg.
1922	125,183	.45	528,000	0.1%
1923	406,194	1.43	1,638,000	0.2
1924	1,575,400	4.6	6,178,000	0.9
1925	5,950,000	8.7	26,096,000	3.4
1926	11,950,000	12.7	50,636,000	6.6
1927	15,950,000	15.8	67,017,000	7.5
	35,959,527		152,105,000	

The production of cracked gasoline from the Cross units in the United States should be over 18,000,000 barrels in 1928. That means the conservation of more than 75,730,000 barrels of crude oil or at the rate of 207,000 barrels a day, based on the 23.8% gasoline recovery from crude by refining in 1927. Cross units have also been installed in foreign countries which have a charging capacity in excess of 15,000 barrels a day.

It has taken several years to increase the efficiency of the Cross cracking process from a production of less than 25% gasoline from the charging stock in 1921 to upwards of 70% at this time. The present rate of gasoline recovery depends on the grade of the charging stock used and the kind of products desired.

The first commercial unit of this process produced a synthetic crude which was redistilled. In 1923, the apparatus was improved so that benzine could be produced. Gasoline was obtained from this product and this comprised the second step in the development of the process. The present improved Cross apparatus produces a cracked gasoline which does not require redistillation or further treatment, except such as is necessary to give it the proper color and odor.

The original commercial Cross cracking unit had a daily charging capacity of 600 barrels. Units of 1,000 barrels were then made. The new ones have a daily capacity of 2,000 barrels and even larger sizes have been developed.

Other Cracking Processes.

OTHER COMMERCIAL cracking processes have been developed and are in operation in the United States. Their estimated total daily charging capacity is shown in the next table.

TABLE 30.

ESTIMATED TOTAL DAILY CHARGING CAPACITY OF OTHER COMMERCIAL CRACKING PROCESSES.

	Barrels
Dubbs Process, licensed to about 50 different companies..	175,000
Gulf-McAfee, owned and operated by Gulf Oil Company	76,000
Isom, owned and operated by Sinclair Oil	70,000
Jenkins, licensed to about 15 companies	30,000
Coast and another, owned and operated by Mid-Continent Petroleum Company	15,000
Miscellaneous	50,000
Total	416,000

The production of cracked gasoline by these various processes should have been approximately 35,000,000 barrels in 1927. They conserved about 147,000,000 barrels of crude oil in that year, or at the rate of 402,000 barrels a day, based on the 23.8% of gasoline recovery from crude oil by refining in 1927.

The Companies in the oil industry have never been content with merely finding a cracking process and then resting on their laurels or anchoring themselves to the results obtained in the first few years. They have made a progressive and aggressive continual search at their own

enormous expense, to improve cracking methods, increase the yields, lower the costs and modify the processes and equipment so that cracked gasoline can be produced economically, efficiently and of such high uniform standard as to fill its present important place in our industries.

It took ability, confidence, courage and a willingness to pile millions upon millions of dollars into research work and new construction in order to bring about the present position of the cracking plants and the high quality of cracked gasoline.

Probably the processes would have been junked long ago if better products had not been developed than those originally made.

Litigation Troubles as to Cracking Processes.

THE PRINCIPAL litigation which has arisen in regard to the cracking patents was the action brought on June 25, 1924, by the Federal Government against Standard Oil of Indiana, Standard Oil of New Jersey, The Texas Company and Gasoline Products Company, designated as the primary defendants, and their licensees, for the alleged violation of the Federal anti-trust laws through certain agreements made by these primary defendants and other alleged acts, and for the cancellation of certain patents owned by these primary defendants on the ground that they had been anticipated by prior patents.

The first contract complained of was the one between Standard of Indiana and The Texas Company, dated August 26, 1921, wherein the patent rights of each company were defined, the licensees of Standard of Indiana were granted immunity for any infringement claim under The Texas Company's patents, the royalties received and to be received by Standard Oil of Indiana under the licensees then authorized were to be shared in by The Texas Company and the royalties collected by either company under licenses thereafter granted under the patents of both companies were to be equally divided.

Next was the contract of January 26, 1923, between The Texas Company and Gasoline Products wherein the Cross patent was defined and the Gasoline Products Company was authorized to grant licenses under the patent rights of The Texas Company, which was to receive a royalty for all operations carried on under the Cross process. The

Texas Company further agreed to make no claim for infringement of its patents against the licensees of the Cross process who took the benefit of the agreement, and to negotiate with Standard of Indiana and Standard of New Jersey for the acquirement by Gasoline Products of a license under their patent rights; upon the securing of such rights, Gasoline Products was to pay an additional royalty to The Texas Company.

As a result of these negotiations between The Texas Company and Standards of New Jersey and Indiana, the seven contracts of on or about September 28, 1923, were made between The Texas Company, Standards of New Jersey and Indiana and Gasoline Products which settled the controversies between them and whereby The Texas Company secured licenses for Gasoline Products from these Standard Oil Companies.

These seven contracts of September 28, 1923, were also the subject of attack in the Government action. They defined the Burton, Tube, Tube and Tank, Holmes Manley and Cross processes. Each company licensed the others to use its patent rights, both in the United States and in foreign countries, and all past infringements against the licensees of the Cross process were waived.

The events which led up to the making of these agreements are very important for their proper consideration.

While the Burton patents of the Standard Oil of Indiana were the first ones issued and had been obtained in 1913 and 1914, yet the earliest applications had not been filed in the patent office until July 3, 1912. The Adams patents which were acquired by The Texas Company were issued in 1919, 1920 and 1922, but the applications for some of them had been filed in the patent office in December, 1909, and in March, 1911. These Adams applications therefore antedated the earliest Burton one by from one year and three

months to two years and seven months and they covered the distillation of petroleum under pressure.

Late in 1919, after the claims in one of the Adams patents had been allowed, the attorney for The Texas Company advised it that these allowed claims were infringed by the Burton process and The Texas Company thereupon notified Standard of Indiana to that effect. The latter promptly gave notice to The Texas Company that the Adams process, then incorporated in the Holmes Manley one, infringed certain patents that it owned. The attorneys for Standard of Indiana knew that the Adams application antedated those of Burton, but they could not determine how far back Adams would be able to carry his date of invention.

After a careful study, the attorneys of The Texas Company came to the conclusion that certain features of the Holmes Manley process did infringe some of the patent rights of Standard of Indiana and they so advised the Company. Both of these powerful companies recognized that the result of any litigation between them might show that each company was infringing some patent right of the other and that neither company might be able to carry on or further develop its process without the consent of the other. Furthermore, Standard of Indiana found that The Texas Company was developing a very promising continuous type of cracking which it might find very advantageous to use and the settlement of the differences between these companies therefore appeared advisable, if not necessary.

In the arrangement which The Texas Company had made with Mr. Adams when it had agreed to take over his patents, he was entitled to one-half the income received by the Company as damages or royalty on account of the infringement of his patents or the granting of rights under them. The Holmes Manley process had not then been licensed to others and it was for the financial interest of both The Texas Company and Mr. Adams that they begin

to receive royalties as soon as possible and to collect damages for any infringement that had been made on the patents.

Standard Oil of Indiana had granted twelve licenses for the use of the Burton process in 1914-1920, inclusive, and had received over $15,000,000 in royalties up to December 31, 1920. That amount was equal to about 25% of the profits made by its licensees through the use of the Burton process, according to the testimony in the patent suit, so that the approximate profit made by these licensees amounted to $60,000,000 to that date. Furthermore, Standard of Indiana had guaranteed these licensees against infringement actions.

During the years of its operation of the Burton process up to 1921, Standard of Indiana itself had manufactured approximately 36,870,000 barrels of cracked gasoline, which was equal to 116.8% of the total amount produced by its licensees. On the basis that its profits were the same per barrel as those of its licensees, Standard of Indiana's net gain from this cracked gasoline would have amounted to around $70,080,000. The total profits of the Company and its licensees appear to have been approximately $130,,080,000 to January 1, 1921, through the use of the Burton process.

If The Texas Company had been able to maintain its position as to the alleged infringement by Standard of Indiana and its licensees of the Adams patents, then this Standard Oil company might have been called upon to pay this estimated sum of $130,080,000 of net gain to The Texas Company. But even this large amount does not include any profits after December 31, 1920, by Standard Oil of Indiana and its licensees through the use of its well established Burton process and such further profits might have been far greater than those already made.

These sums were very substantial for any Company to pay or to jeopardize and little blame can be put on Standard

of Indiana for settling its differences with The Texas Company and executing the agreement of August 26, 1921, after negotiations which covered more than a year. Normal human beings would probably consider it the wisest way out for each company.

That contract created no limitation upon the freedom of action of either company or on its control of its own process and patents. There was no restraint on the licensing of either process to others or on its use by the owning company and its then licensees. Either company could grant as many more licenses as were deemed advisable. Competition was not restrained or prevented as between these companies and there was no restriction on the production of cracked gasoline or agreement as to its selling price. Each Company acquired the benefit of the research work and improvements of the other and its progress in the development of the cracking art and the resultant further conservation of crude oil was accelerated.

The execution of this agreement appears to have been the most sensible thing to do. It showed a spirit of cooperation on vital matters between these companies in their effort to avoid very expensive litigation and possibly heavy damages and in doing anything which would prevent the continued use, development and installation of their cracking processes, processes which had then become and which have since been so necessary in order to meet the ever increasing demand for gasoline without excessively depleting our national crude oil reserves.

The next contract attacked in the Government suit was the one between The Texas Company and Gasoline Products Company of January 26, 1923. While The Texas Company and Standard of Indiana and its licensees continued their own very substantial development and installation of the Burton and Holmes Manley cracking processes, it appears

that a complicated situation arose on or about May 9, 1922, when the first of the Ellis patents for a cracking process was issued to Standard Oil of New Jersey, assignee. The application for this Ellis patent had been filed in the patent office on October 4, 1913. Within a short time after the patent was issued, Standard Oil of New Jersey began an action against the Pure Oil Company, one of the licensees of Gasoline Products, for infringement of the Ellis patent. The Texas Company realized that it also was affected by this Ellis patent as it covered the "once through coil and drum type" of operation which was practiced in the Holmes Manley process, and it intended to install a large number of these units. Subsequently, other Ellis patents were issued affecting the refining of gasoline which were assigned to Standard of New Jersey and which The Texas Company desired to use.

At this junction, another serious development took place. A suit had been brought in New York County by one George T. Rogers against The Texas Company and Joseph H. Adams, the inventor of the Adams process, in which Rogers claimed a 40% interest in the Adams inventions and patents through a contract which he had made with Mr. Adams in July, 1907. In this contract Mr. Rogers had agreed to advance money to assist Mr. Adams in completing his invention of apparatus and processes for cracking oil and obtaining patents therefor and Mr. Adams had agreed to grant him a 40% interest in such inventions and patents.

In July, 1922, the Supreme Court decided in favor of Rogers and against both Adams and The Texas Company, the latter on the theory of constructive notice of the Rogers interest. The Court held that Rogers was the owner of an undivided 40% interest in Adams's inventions and patents, that Adams had no right to dispose of or to license the same without the consent of Rogers, and that the latter was entitled to an accounting from both Adams and The Texas

Company of their gains and profits derived from these inventions. Both defendants were enjoined from using the process and making licenses for its use by others without the consent of Rogers.

During the trial of this action, it developed that Standard Oil of New Jersey had obtained a contract from Mr. Rogers for the assignment to it of all his right, title and interest in the Adams patents. The Standard of Indiana, as a licensee under these Adams patents and of the Holmes Manley process, was liable to Standard of New Jersey for 40% of any gains and profits derived from the Holmes Manley process and The Texas Company had guaranteed it against attacks on this process.

The Pure Oil and Rogers suits therefore again brought an outstanding element of doubt and uncertainty into the patent situation. After the suit against Pure Oil had been brought, Gasoline Products had begun negotiations with The Texas Company in order to induce it to contribute to the defense of the action, as the latter was also affected by the Ellis patents. Furthermore, it was brought to the attention of The Texas Company that a British patent had been issued to Standard of New Jersey which indicated that a similar application was then pending in the United States patent office.

Such an application might contain a claim covering the heating of the charging stock in a tubular member or coil of pipe and deferring the bulk of the cracking to a large reaction chamber where no heat or only a moderate amount was applied. This feature was always regarded as of utmost importance in the Holmes Manley process and applications for patents had been filed to cover it. If such a claim had been made by Standard of New Jersey, then interferences might arise in the patent office with the final result in grave doubt.

About this time Gasoline Products had issued a booklet advertising its Cross process, wherein these Cross patents were interpreted in somewhat of a new light and one disturbing to The Texas Company. It stressed the feature of putting heat into the oil in the tube or coil and yet deferring cracking to the subsequent reaction chamber. This interpretation of the Cross patents was in conflict with certain steps in the Holmes Manley process. There were also serious interferences in the Patent Office between these two companies over pending applications and the result was doubtful. They might be decided either way so that either company might dominate the operation of the other's cracking process.

All in all, they comprised a very serious complication. Negotiations had been opened between Standard of New Jersey and The Texas Company for the settlement of their respective rights in the Adams patents. Before they were concluded, the Appellate Division of the Supreme Court unanimously affirmed the decision in favor of Rogers in the Rogers-Adams suit. This unanimous decision settled the facts in the litigation and no further appeal could be made except as to matters of law, and it strengthened the position of Standard of New Jersey immeasurably.

The Texas Company was not in a very happy situation. It had kept its negotiations with Standard of New Jersey and Gasoline Products separate. The next annoyance came when it received information from the President of Gasoline Products that he also was negotiating with Standard of New Jersey and that he expected to conclude an agreement with either the Texas or New Jersey company.

All these various difficulties apparently acted as a stimulant on the negotiations between The Texas Company and Gasoline Products and the contract between them was executed on January 26, 1923. This agreement did not limit

the rights of either Company in the developing or licensing of its process.

Fortunately for the entire cracking situation, as well as for the further conservation of crude oil through cracking and the supplying of sufficient gasoline at a reasonable price in order to meet its ever increasing demand, The Texas Company and Standard of New Jersey were able to come to an agreement in September, 1923, through which their rights were defined and the Rogers interest in the Adams patents was assigned to The Texas Company. This is one of the contracts under attack in the patent suit.

This agreement embodies the tentative proposition made by Standard of New Jersey to Texas before the Rogers-Adams-Texas Company decision was unanimously affirmed by the Appellate Division. Notwithstanding the greatly improved position of Standard of New Jersey through the finding of all the facts in its favor and the impossibility of reviewing them by the Court of last resort, its terms to The Texas Company were the same as the tentative ones made before the affirmance of the decree.

Here again, we find a spirit of cooperation and fair play between these two powerful oil companies which leads us to believe that a cooperation, both healthful for the oil industry and of vital importance in the creation and conservation of crude oil reserves for the generations to come, may be developed in the crude oil production situation, if the companies are relieved from possible prosecution under the Federal anti-trust laws.

The six other contracts of on or about September 28, 1923, followed this Texas-Standard of New Jersey agreement. They prevented an extended, expensive and annoying litigation between these companies and against their licensees, and the Pure Oil suit was thereafter discontinued.

While these settlements of the differences between these four powerful and resourceful organizations have been un-

doubtedly of great benefit to each of them, the public other than the stockholders of the respective companies, are not especially interested in such matters. But these very settlements and the making of these contracts have been of great public importance in the conservation of our crude oil resources and in keeping down the price of gasoline to or below reasonable levels.

If Standard of Indiana and The Texas Company had not made the 1921 contract there probably would not have been the intensive development and installation of either the Burton or Holmes Manley cracking processes which have since taken place. Probable licensees of either process would have thought many times before placing themselves in a position of becoming a party to litigation between these companies. The public interest and good, in as far as they comprise the conservation of crude oil effected through the Burton and Holmes Manley cracking processes, would have suffered immensely, especially as the great development of the Holmes Manley and the use of a modified process by Standard of Indiana would probably not have taken place until years of litigation came to an end.

As illustrative of this progress, the expansion of the Holmes Manley since 1921 by The Texas Company alone to a point where it is now producing over seven times the amount of cracked gasoline produced in 1921 is shown in Table 25.

The extension of the Holmes Manley and Cross processes would have been delayed if the agreements of 1923 between these four companies had not been made. When the suit by Standard of New Jersey against Pure Oil, licensee of the Cross process, was instituted in 1922, pending negotiations for the use of the Cross process and further installations by the then licensees were held up. The big extension of the Cross cracking units to a present charging capacity of

over twelve times that of December 31, 1923, is shown in Table 29.

Tube and Tank installations would probably have been delayed as either The Texas Company or Standard of Indiana might have been awarded the basic patents covering the use of pressure in cracking. Other patent rights might have been found to belong to either of these companies or to Gasoline Products under which claims of infringement might have been litigated. The Tube and Tank units are now producing over 25 times the production of 1923, see Table 27.

Not one of these four cracking processes appears to have been free from conflicting claims with the others and there are approximately 118 adverse or overlapping claims in the patents owned by these four companies.

Principally through the development of the Holmes Manley, Tube and Tank and Cross cracking processes and the avoidance of litigation by the owner of the Burton process and its licensees, the public have had an ample supply of gasoline at very reasonable prices. Reading backwards from the actual achievements, there would have been a dearth of gasoline had not the capacities and output of cracked gasoline by and through these cracking processes been increased many fold.

The effect of these agreements can be realized by looking at Table 23 and considering the increased production of cracked gasoline in 1927 of over 4 7/10th times that of 1921, and of 3½ times that of 1923. It would be difficult to estimate the public loss through the increased prices of gasoline if these companies had not wisely settled their differences.

Had not these contracts been made, the amount of additional crude oil which it would have been necessary to produce and refine in order to supply the gasoline produced through the improvements and new installations of these processes since 1921 or 1923 would have brought about an

excessive depletion of our crude oil reserves and a very large overproduction of other refined products.

It is through these agreements, too, that other refiners can choose one or more of these four very efficient cracking processes for use in their plants at very reasonable royalties, without running the risk of infringement suits by any of the four companies.

Suits are pending by the owners of other cracking processes. But all the many claims in the patents owned by these four companies and their powerful resources are arrayed against the possibility of any one company obtaining a monopoly of cracking processes and of any such company getting the benefit of the years of research and hundreds of millions of dollars spent by these four companies and their licensees in the development and installation of the four cracking processes. An even more powerful ally than their patent claims and great financial resources is the overpowering sense of public justice and general welfare which have been reflected at times in the decisions of our highest Court.

Each of these four powerful companies, Standard Oil of Indiana, The Texas Company, Standard Oil of New Jersey and Gasoline Products, has through these agreements forever estopped itself from obtaining a monopoly of cracking processes through its patents and thereby forcing all other oil companies to pay the tribute which could thereby be levied and exacted.

The outstanding features of these patent agreements are the intelligence and business sagacity displayed by the officials of the companies in getting together for cooperative effort along constructive lines which have resulted in the conservation of so much crude oil, in eliminating the losses and expense of litigation and in preventing the consequent delays in improving the quality of cracked gasoline and the further erection of plants for its production. Such coopera-

tion is probably legal in view of the monopoly features of a patent granted by the Federal Government.

Patents, in the ultimate analysis, give the owners an opportunity to spend large sums in order to make them commercially practical. They also act as an invitation to others for the bringing of litigation against the owners and to infringe upon their rights. Opportunities arise for others to try to evade these patents by reading or interpreting the ancient and expired ones in the light of present day knowledge, which was probably never intended by our patent laws.

The cooperation effected through these patent agreements has done much to prevent litigation or threats against licensees of any of the processes. It provides them with such powerful backing both of patent claims and other resources, that they could and did go ahead with confidence in increasing their cracking installations.

If these agreements had not been made, further improvements in the cracking of gasoline might have been stopped and the construction and erection of cracking equipment curtailed, both by these companies and their licensees. The operation of the installed units by some might have been discontinued and prospective licensees would have thought a long time before spending the large sums necessary for the erection of cracking plants.

The risk of being continually served with infringement claims by one, two or three of these companies and possibly subjected to expensive litigation and heavy damages was such that no one using a cracking process of any one of these companies could feel certain of the outcome of litigation extending over a long number of years.

Assuming, as appears reasonable, that the pending and threatened litigation as to the patents of these four cracking processes had stopped all further construction of Burton, Holmes-Manley, Tube and Tank and Cross cracking units since December 31, 1923, the production of cracked gasoline

in the United States would have been approximately 109,-426,000 barrels less than were actually produced since then. On the 1927 basis of the refinery recovery of gasoline to crude oil, that amount of decreased production of cracked gasoline would have required the refining of an additional 459,748,000 barrels of crude oil, or over 50% of the 1927 production.

Elimination of Former Waste of Cracked Gasoline.

THE PERCENTAGE of the recovery of gasoline from the charging stock by some of the cracking processes has been increased three or more fold since the installation of the first commercial units. By far the largest part of this increased efficiency is the result of improvements in the construction and operation of the plants but a substantial amount has come about through a better understanding of the nature and properties of the cracked gasoline itself.

For years, there was a strong prejudice against the use of cracked gasoline because it contained hydrocarbons which were not present to any large amount in the straight run gasoline made by refining. This same aversion was felt for any motor fuel which consisted of a blend of cracked and straight run gasoline. Manufacturers and sellers of straight run or unblended gasoline constantly advertised the alleged superiority of their products and stated that cracked gasoline contained deleterious constituents which were not present in straight run. The public became firmly convinced that such alleged superiority did actually exist and that blended gasoline should not be bought if straight run could be obtained.

The chief objection claimed against cracked gasoline consisted in the inevitable presence of a considerable volume of olefins or unsaturated hydrocarbons which were pointed out as the undesirable elements for internal combustion engines. Until recent years many inventors and some oil companies endeavored to produce a gasoline which did not contain these unsaturates or they tried to combine other processes with cracking in order to prevent or minimize their formation. Steam was mixed with the oil vapors or a catalyzing agent was introduced in order to provide free hydrogen for the saturation of a considerable amount of these

unsaturates. The combined use of steam and a catalyzing agent was also tried out.

Up to 1920, it was generally reported and believed that the chief drawback to all cracking processes was the production of this large volume of unsaturates which was necessarily made by all such processes. Although certain investigations indicated and it was recognized by some that a properly made cracked gasoline gave greater power and mileage and that it was superior to straight run or unblended gasoline for motor use.

In recent years investigations have proved not only the superior qualities of cracked gasoline, but that they are due principally to the presence of these unsaturated hydrocarbons. They give to the cracked or blended gasoline the important anti-knock qualities which they are now known to possess.

These unsaturates constitute up to 20% in volume of the gasoline produced through cracking, according to the characteristics of the charging stock used and the method of cracking. For a number of years after the introduction of cracking, these unsaturates were removed by the use of strong sulphuric acid so that the volume of the finished product was diminished up to 20%. Some losses from washing with sulphuric acid were reported to be as high as 50% in 1916.

This was a distinct economic loss. It was founded on ignorance and the resultant prejudice. Fortunately, it has been overcome through the realization of the true properties of the unsaturates. These formerly despised and rejected products of cracking have since become the most important elements of gasoline. They form the base of many of the premium gasolines which have an extensive sale throughout this country.

There are still some impurities in raw or untreated cracked gasoline, the same as in straight run, consisting

principally of the gum forming constituents and sulphur compounds. The latter are present in undesirable quantities where the charging stock used has been produced from a high sulphur content crude oil. Originally, a strong sulphuric acid treatment was used for the removal of these impurities. But in treating cracked gasoline it has been found that a weaker acid treatment will remove the impurities and prevent, to a large extent, the destruction of the unsaturates. Treatment losses have therefore been reduced to 4% or less of the volume except where redistillation of the cracked distillate is necessary. A further loss up to 4% of volume occurs through the rerunning of these distillates.

Some of the cracking processes produce almost a finished gasoline which does not have to be treated with acid or redistilled. Other processes have been installed in some refineries in connection with the cracking units whereby impurities are extracted out of the vapors before they condense into gasoline.

All in all, probably around 15% of the total volume of cracked gasoline which was formerly lost through redistillation and the removal of the unsaturates or by their destruction in the heavy acid treatment for the purification of the raw product is now saved by the improved cracking processes and by the use of other means to remove the impurities.

This constitutes an important conservation of one of the principal products of crude oil.

The percentage of unsaturates in cracked gasoline depends on the temperatures and pressures used during the period of cracking. For a stated pressure their percentage appears to increase at higher temperatures, while for a given temperature this percentage decreases under lower pressures. At this time the oil companies are developing improvements for the creation of a larger percentage of these unsaturates in cracked gasoline.

Non-Condensible Gases and Decreased Consumption of Fuel Oil at Refineries.

One of the undesirable and unavoidable results of cracking is the formation of non-condensible, permanent or fixed gases which cannot be liquefied into gasoline or any other refined product. The amount of these fixed gases which are necessarily produced is of considerable importance in the cracking art, as too great a yield means a substantial loss of gasoline and an excessive cost of manufacture. Less fixed gases are produced by bulk pressure stills than by tube cracking.

These non-condensible gases are created by the continued decomposition of the gasoline and other hydrocarbon vapors and are formed during the cracking operation. Their volume increases with higher temperatures and the longer retention of the vapors in the cracking zone. It is therefore advisable to force out or withdraw these vapors comprising the gasoline fractions as quickly as possible from the cracking zone, so that only a small amount of non-condensible gas will be formed. Different grades of crude oil appear to have little or no effect on the volume of fixed gas produced, and it depends on the physical factors of operation.

These non-condensible gases do contain a small percentage of gasoline which cannot be liquefied in the condenser which constitutes a part of the cracking unit. This gasoline, however, can be extracted in absorption gasoline plants and it is recovered in the modern refineries which have installed gas collecting systems.

Fixed gases were formerly considered waste matter, but

they are now utilized as fuel in the operation of refining and cracking plants. This use has brought about one of the important economies effected in refineries during the past few years. It has resulted in a substantial reduction of the refinery use of coal and fuel oil, which have been replaced to some extent by the utilization of these fixed gases and the dry natural gas from casinghead gasoline plants.

Every section of the United States has recently shown a gain in the use of these fixed gases which comprise the principal part of the refinery gas used as fuel at the refineries. Some non-condensible gas is formed in other refining operations, but it is a minor amount compared to that made in the cracking processes.

The increase in the use of refinery gas as well as stripped natural gas is shown as follows:

TABLE 31.

GAS USED AT REFINERIES FOR FUEL, IN CUBIC FEET.

Year	Refinery Gas	Natural Gas	Total Gas
1926	52,077,000,000	121,449,000,000	173,526,000,000
1925	35,041,000,000	87,842,000,000	122,883,000,000
Increase, amount ..	17,036,000,000	33,607,000,000	50,643,000,000
" percentage	48.6%	38.3%	41.2%

This increase in the utilization of refinery and stripped natural gas as fuel resulted in a reduction in the use of fuel oil and a slight decrease in the coal requirements, shown in the next table.

TABLE 32.

FUEL OIL AND COAL CONSUMED AT REFINERIES.

Year	Fuel Oil, Barrels	Coal, Short Tons
1926	46,416,000	6,052,000
1925	50,455,000	6,153,000
Decrease, amount	4,039,000	101,000
" percentage	8.0%	1.6%

But the foregoing table does not indicate the real decrease in the consumption of fuel oil per barrel of crude oil refined, as there was a substantial increase in the throughput of crude by refineries in the United States in 1926. In that year only 596/10,000 part of a barrel of fuel oil was consumed for each barrel of crude refined, compared to 682/10,000 part of a barrel in 1925, a decrease of 12.6%, which is rather remarkable for only one year. Based on the 1925 consumption of fuel oil at refineries per barrel of crude refined, it would have been necessary to consume 53,145,805 barrels of fuel oil in 1926, or 6,729,805 barrels more than were actually used. It can well be concluded then that at least these 6,729,805 barrels of fuel oil were conserved for other uses in 1926 over that of 1925 through the increased use of refinery gas and stripped natural gas. That is at the daily rate of 18,438 barrels.

Based on the heating values of refinery gas and stripped natural gas, and fuel oil, the amount of refinery and natural gas used as fuel at refineries in 1926 represented over 30,000,000 barrels of fuel oil.

The largest increase in the use of refinery gas as fuel and the total decrease in the consumption of fuel oil at refineries occurred in the group of states in which the production of cracked gasoline had increased to a greater extent than in the remainder of the United States. A comparison is shown in the next table.

TABLE 33.

PRODUCTION OF CRACKED GASOLINE AND CONSUMPTION OF REFINERY GAS AND FUEL OIL AS FUEL AT REFINERIES IN GROUPS.

Cracked Gasoline Produced in Barrels.

Year	Missouri, Kansas, Oklahoma, Texas, Arkansas and Louisiana	Remainder of United States	Total United States
1926	45,736,000	48,000,000	93,736,000
1925	32,887,000	35,696,000	68,583,000
Increase, amount	12,849,000	12,304,000	25,153,000
" percentage	39.1%	34.7%	36.7%

Refinery Gas Consumed in 1,000 Cubic Feet.

Year	Missouri, Kansas, Oklahoma, Texas, Arkansas and Louisiana	Remainder of United States	Total United States
1926	26,382,000	25,695,000	52,077,000
1925	17,117,000	17,924,000	35,041,000
Increase, amount	9,265,000	7,771,000	17,036,000
" percentage	54.1%	43.4%	48.6%

Fuel Oil Consumed in Barrels.

Year	Missouri, Kansas, Oklahoma, Texas, Arkansas and Louisiana	Remainder of United States	Total United States
1926	21,232,000	25,184,000	46,416,000
1925	25,974,000	24,481,000	50,455,000
Decrease, amount	4,742,000	....	4,039,000
" percentage	18.2%	....	8.0%
Increase, amount	....	703,000	....
" percentage	....	2.9%	....

The refinery and natural gas used also show a substantial increase in the percentage of heat units consumed while that of coal and fuel oil decreased. Percentages of British thermal units contained in these fuels to the total amount in all fuel consumed at refineries follow:

TABLE 34.

	Percentage of B. T. U.'s to Their Total Number in All Fuel Used at Refineries		Percentage of Increase or Decrease in 1926 Over 1925
	1925	1926	
Refinery gas	6.1%	8.7%	42.6% inc.
Natural gas	15.3	20.2	32.0 "
Coke	1.6	1.9	18.8 "
Coal	26.6	25.0	6.0 dec.
Fuel oil	50.4	44.2	16.5 "
	100.0	100.0	

Records of fuel consumption by refineries show that the oil industry has been constantly decreasing its relative use of coal, the fuel which is so situated that it is more available for other industries than these others. Since 1919, the oil industry has also decreased its proportionate use of fuel oil, the other fuel which can be easily transported to industrial centers.

The greater utilization by refineries, first of natural gas and then of stripped natural gas and refinery gas is shown in Table 35, as well as the decreasing relative consumption of coal since 1914 and of fuel oil since 1919. In the years 1914 and 1919, the amount of refinery gas used as fuel was negligible. It was a waste product and considered of no value.

The next table also sets forth the number of barrels of fuel oil which contain the same number of heating units as possessed by the natural and refinery gas consumed by the refineries. It indicates how the utilization of these gas fuels has conserved fuel oil for other industries.

TABLE 35.

PERCENTAGES OF B. T. U.'S IN THE DIFFERENT FUELS CONSUMED BY REFINERIES TO THE TOTAL B. T. U.'S IN ALL FUELS USED AND THE AMOUNT OF FUEL OIL CONTAINING THE SAME NUMBER OF HEATING UNITS AS THE REFINERY AND NATURAL GAS CONSUMED.

Fuel	1914	1919	1926
Refinery gas	neg.	neg.	8.7%
Natural gas	7.5%	8.9%	20.2
Coke	3.1	3.2	1.9
Coal	60.4	41.4	25.0
Fuel oil	29.0	46.5	44.2
Total	100.0	100.0	100.0

Barrels of fuel oil containing the same number of heating units as the refinery and natural gas consumed:

1914	1919	1926
1,923,906	4,710,834	30,367,167

The 1926 equivalent in fuel oil comprises 83,198 barrels of fuel oil a day conserved for other industries through the use by refiners of these formerly wasted gases, products which could be utilized as fuel to a very small extent only by other consumers.

But any conclusion drawn from the preceding tables and figures would be wholly inadequate. It would present a very poor picture of the real progress of the refining industry during the past few years in conserving the use of both coal and fuel oil for other industries.

In 1919 there were 849,000 B. t. u.'s consumed as fuel at refineries for each barrel of crude oil refined. They had been reduced to 809,000 in 1926. While that is a decrease of only 4.7% in seven years, the following important factors must be taken into consideration:

The much higher temperatures and greater number of B. t. u.'s required in 1926 for the production of 93,736,000 barrels of cracked gasoline compared to only 15,486,000 barrels in 1919. Approximately 642,000 barrels a day of fresh charging stock were run through the cracking plants and raised to temperatures of from 750 to 850 or more degrees Fahrenheit under heavy pressure in 1926 compared to approximately 142,000 barrels a day at temperatures not exceeding 750 degrees Fahrenheit and at lesser pressures in 1919. Furthermore, an additional 350,000 barrels a day or so of this charging stock was rerun or recycled through the cracking units in 1926 and very little of this was done in 1919. The heat requirements of 1926 per barrel far exceeded those of 1919.

The ever growing practice of *completely* refining crude petroleum which has taken place since 1919 necessitated the use of much higher temperatures and many more B. t. u.'s per barrel than the old skimming plants.

Were it not for the much greater present efficient utilization of heat units by refineries through the use of hot still gases for preheating the air for fuel combustion and the feed water for boilers; by means of heat exchangers through which the cold oil absorbs the heat of still gases, cracked vapors and hot liquids; through the use of heat economizers which utilize the heat units in flue gases and the heat economy of tubular stills; and were it not for the utilization of the formerly wasted refinery gas and stripped natural gas, it is probable that the 1926 consumption of fuel oil by refineries would have been about double the per barrel requirements of 1919. On that basis, the conservation of fuel oil effected through the progress made by the refining industry should be now running at the rate of over 54,000,000 barrels a year or an average of 148,000 barrels a day. That represents a further very important saving of crude oil.

While this non-condensible gas necessarily produced in the cracking of oil is now utilized as fuel by the modern refineries and is not wasted as was formerly done, it may become one of the valuable products of cracking. Its heating qualities are somewhat greater than those of natural gas and far superior to the water gas manufactured in many cities.

These non-condensible gases contain from 1,050 to 1,200 B. t. u.'s per cubic foot compared to 500 or 600 in water gas. As the laws require from 900 to 1,000 B. t. u.'s in artificial or manufactured gas before it can be sold, water gas must be enriched by the use of gas oil or other means.

For some time it has been pointed out that manufacturers of water gas who are able to obtain this non-condensible gas at reasonable prices can utilize it for the enrichment of their water gas at a lesser cost than by purchasing and vaporizing gas oil. This fixed gas has been sold for some years by certain cracking plants situated in or near cities where water gas is manufactured. As high as 32 cents per 1,000 feet is obtained. That gives a fair return for a by-product formerly non-salable and not produced as one of the desirable objects of cracking. This matter is well worth further study and consideration. The greater use of these gases for this purpose will result in the saving of an important barrelage of gas oil and the conservation of crude.

Evaporation Losses and Their Reduction.

One of the former largest losses or waste of crude oil came about through the evaporation of crude petroleum after it was taken from the wells. These losses occurred in every branch of the oil industry and were more or less continuous until the refined products were finally distributed. Most evaporation losses resulted from the use of open tanks, non-vapor tight tanks and those with wooden roofs.

General evaporation losses include those from the spray which was carried away by the air as the tanks were filled with crude oil from overhead pipe connections. This was a needless waste and one which was frequently quite large.

They also include ebullition losses that resulted when crude oil which contained gas, and sometimes air, was forced into the tanks through connections at the bottom. The gas and the air arose through the oil in the form of bubbles which broke at the top of the liquid. The finely divided particles of oil were thus projected into the air and vapor above the crude and were whipped away in such vapor form. Some of the particles of oil were so light that they were carried off as liquid from tanks which were nearly full.

Evaporation losses proper consisted of that part of the oil which became vaporized and arose from the surface and was dissipated and lost into the atmosphere under former handling and storage conditions.

Opportunities for the loss of this vapor can be shown by tracing the crude oil from the wells. After being brought to the surface of the ground, the crude was run through pipes under pressure into the stock, flow, settling or receiv-

ing tanks situated on the leases. This crude contained considerable gas and sometimes air and water but there was no chance for its evaporation in these pipes.

The gas and air were separated from the crude oil in these settling tanks some of which were capped with nearly vapor tight covers. Short stacks were fitted in these roofs through which the gas escaped into the air. Where water and basic sediment were contained, they were separated from the crude oil in either wooden or steel unhoused or unprotected tanks without roofs or with very poor ones. Important evaporation losses occurred from these tanks.

Where over 2% of water was emulsified in the oil, it was necessarily to use some special means for breaking up the emulsion so that the water could free itself through gravity. Electricity, chemicals, centrifugal force and heat were used to effect this separation. All these means necessarily involved some evaporation of the crude, but it was comparatively small except when heat was used in the dehydration plants.

After the oil had passed through the settling tanks and the dehydration of plant if necessary, it was run into the storage tanks on the leases which had a capacity of from 60 to 1,800 barrels each. While in these lease storage tanks, important evaporation losses occurred as the oil was held for an average of five days before it was taken into the pipe lines, and the roofs of these tanks were not vapor tight. The largest amount of evaporation took place from these lease storage tanks, except where dehydration by heat was used.

From these lease storage tanks the crude oil was then run through the small gathering pipe lines into the pipe line storage tanks. No evaporation could take place in the pipe lines, but some loss from ebullition did occur when the crude was forced under pressure into the pipe line storage tanks. However, they were larger and of a better type than

the lease storage ones and their roofs were more or less gas tight.

After the oil had stood in these pipe line storage tanks, it was then run through the large main or trunk pipe lines or into tank cars for transportation to the refineries or to large tank farms. In its passage through the trunk pipe lines, the oil passed through a number of pumping stations. Originally, all the oil was pumped into and withdrawn from storage tanks at the pumping stations. So that the crude oil in passing through a long pipe line was flushed into tanks many times, with distinct losses from ebullition and evaporation.

If the crude oil did not go directly to the refineries through the pipe lines, it was stored on large tank farms in 35,000 and 55,000 barrel steel tanks or in much larger earthen or cement ones which were fitted with more or less gas tight roofs. Here the evaporation was much slower. But as the oil was sometimes held for long periods, there was a continuous evaporation loss which decreased from year to year.

The refineries were required to store enough oil to run them for some time and their storage tanks were similar to the ones on the tank farms. Some evaporation losses occurred from these tanks and also in the spent gases from the stills. Very important evaporation losses occurred when it was necessary to store gasoline at the refineries and some losses took place in the filling of tank cars with gasoline.

Evaporation losses were not the same for the various grades of crude oil. The high gravity oils which contain the largest amount of the lighter or gasoline fractions suffered more from evaporation than the heavier ones. An oil which had been standing in tanks for a long time, and which had lost most of its lighter fractions thereby became less subject to evaporation losses until it finally reached a point where further losses did not occur.

A careful survey and study of evaporation losses was made by the Federal Government prior to 1918 and the results were well expressed in its report for that year as follows:

> "If we definitely knew the volume of useful hydrocarbon products that 'vanish into thin air' from the wells, the transportation systems, the storage farms and the refineries in the United States in one single year's time, we might well be staggered by the size of the figures. To form some realization of their gigantic proportions, one needs only to stand in the vicinity of a flowing well newly brought in and witness the volumes of gases rising like exaggerated heat waves from the well itself, from the flow tanks in which the oil is being collected, from the sump into which it has overflowed and from every surface exposed to the atmosphere. The greatest unmeasured loss, of course, takes place in the vicinity of the well. Nevertheless, this loss continues in a large measure, especially as regards light oils, through the gathering systems, the transportation systems and the receiving tanks at the refineries and even from the oil of low gravity, there is a substantial stream of light hydrocarbons escaping from its surface as long as it remains in storage."

This gives a very fair picture of the conditions prior to 1918. Some idea of the loss of volume and the decrease in the gravity of the crude oil by evaporation from the permanent steel storage tanks of that time can be formed from the results of these Government investigations, In Oklahoma and Kansas, where these steel tanks were covered with wooden roofs overlaid with roofing paper and sheet iron, the average losses are shown in the next table.

TABLE 36.

EVAPORATION LOSSES REPORTED IN OKLAHOMA AND KANSAS PRIOR TO 1918 FROM PERMANENT STORAGE TANKS WITH WOODEN ROOFS.

	Average Loss		
First two years	1.83% of volume a year		
Next five years	0.79%	"	"
Following two years	0.39%	"	"

Attendant losses of gravity were from 1.6 to 3.5 degrees Baume. The fresh oil was of an average gravity of 34.4 degrees Baume and this had decreased to an average of 32.4 degrees at the time of the last observation.

A company which handled large quantities of crude petroleum and which operated extensively in Oklahoma and Texas kept its crude oil moving so constantly that exact figures of evaporation losses could not be determined. But they were estimated as follows:

TABLE 37.

ESTIMATED EVAPORATION LOSSES BY A LARGER HANDLER OF CRUDE, FROM OKLAHOMA AND TEXAS OIL, PRIOR TO 1918.

Grade of Crude	Gravity, ° Baume	Annual Loss
Distillate	43 to 50	2.0%
N. Texas and N. La. light crudes	30 to 40	1.5
Gulf Coast heavy crudes	18 to 25	0.7
Oklahoma crude, light	38 to 41	2.5
" " medium	30 to 38	1.0

Data obtained for the preparation of this 1918 Government report from eight 37,500 barrel steel tanks, having wooden roofs covered with tar paper over which sheet iron was nailed, are shown in Table 38. These tanks were filled with Illinois crude of an average gravity of 33.1 degrees

Baume which had remained in storage for four years. The losses shown do not include any evaporation of the crude oil before it had reached these large storage tanks.

TABLE 38.

EVAPORATION LOSSES FROM EIGHT WOODEN-ROOFED STEEL TANKS FILLED WITH ILLINOIS CRUDE, PRIOR TO 1918.

Period Year	Average Loss in Gravity		Average Loss of Volume	
	° Baume	Per Cent.	Barrels Per Tank	Per Cent.
First	0.91	2.75%	1,007	2.766%
Second	.45	1.39	476	1.308
Third	.42	1.32	344	.944
Fourth	.11	.35	215	.588
Total	1.89	5.81	2,042	5.606
Average	.47	1.45	510	1.402

The evaporation losses from certain fresh California crude oil in 1913-1916, inclusive, stored for very short periods of from 5 to 30 days in large steel tanks with wooden roofs, were at the annual rate of between 0.6 and 0.72% for heavy oils of 13.4 degrees Baume and between 11.32 and 20.08% for California light oil of a gravity from 22.9 to 27.9 degrees Baume. In 1913 and 1914 one tank was reported to have shown a loss at the annual rate of 30.07% from crude oil of a gravity from 23.9 to 28.5 degrees while another tank's loss was at the annual rate of 25.2% from oil between 25.9 and 27.5 degrees Baume. These percentages appear to have been excessive and were probably caused by the special conditions of the tanks.

However, the actual yearly losses could not have run as high as these annual rates for these lighter crudes as the evaporation losses during the first month are the largest and they gradually decrease in the remaining months of the year.

A résumé of these investigations of the Bureau of Mines is shown in the next table. They indicate the very substantial conservation effected by the all steel tanks then coming into use over the steel tanks covered with wooden roofs. For 55 to 60 degrees distillate, the savings effected were from 23.44 to 24.04% of the volume a year while on 30 to 38 degrees crude, they were 0.61%.

TABLE 39.

SUMMARY OF LOSSES OF OIL IN STORAGE BY EVAPORATION FROM THE REPORT OF THE BUREAU OF MINES IN 1918.

Gravity of Oil	Type of Tank	Average Yearly Loss	Remarks
55 to 60 distillate	Wooden roofed steel tanks	27.8%	
Ditto	All steel	4.36	Plain top, no water seal
Ditto	" "	3.76	Water seal
43 to 50 "	" "	2.00	
44 to 44.5 crude	Wooden roofed steel tanks	2.02	Pennsylvania crude
38 to 41 crude	All steel	2.50	Oklahoma crude
30 to 38 "	" "	1.00	Texas and La. crude
30 to 38 "	Wooden roofed steel tanks	1.61	Oklahoma and Kansas
33 "	Ditto	1.40	Illinois crude
18 to 25 "	"	0.70	Gulf Coast crude
22 to 28 "	"	15.60	Fresh California crude; annual rate based on a few days' storage
18 "	"	5.52	California crude
14 to 16 "	Unlined earth reservoir, wooden roof	6.96	California crude
14 "	Concrete lined reservoir with wooden roof	.95	California crude
13.4 "	Ditto	.66	California crude

A large seepage loss was included in the 6.96% figure for the unlined earthen reservoir in California. There are no seepage losses from steel tanks or from well constructed concrete lined earthen reservoirs. But there existed in those days some unlined earthen tanks from which these losses were important. The amount of crude which was so wasted cannot be estimated properly, as the oil was not usually measured as it flowed from the wells. Instances are reported where these unlined reservoirs had to be abandoned even in the very heavy crude oil fields on account of these seepage losses. In one case the oil was found to have penetrated into the earth to a depth of over 20 feet in a short time.

In the Kern River field in California the seepage and evaporation losses from heavy oil of between 14 and 16 degrees Baume in a 1,000,000 barrel reservoir which was kept practically full, was found to average 6.96% a year over a period of six years. After this reservoir was lined with concrete, these losses were reduced to an average of 2.112% a year. As oil was being constantly put in and taken out, it appears that the seepage loss which was prevented by the concrete lining amounted to 4.848% a year, or 48,480 barrels. That was an important saving. The cost of this lining was only 5 cents per barrel of capacity, so that the oil saved in one year at $1.00 a barrel practically paid for the concrete lining.

In the years 1912-1916, inclusive, covered by this report, the progressive companies in the oil industry were not only trying to but were actually conserving crude oil and the high gravity distillates by reducing these evaporation losses through the erection of all steel tanks instead of the wooden roofed ones commonly used. This saving as shown in Table 39 amounted to 84.3% of the previous losses of high gravity distillate and to 37.9% of those of high gravity crude oil.

Experiments were also being made with water sealed roofs. Tanks were built with a flat roof, riveted and caulked and made water tight, and placed about six inches below the tops of the sides of the tanks. Water was kept in constant circulation on these roofs which reduced the temperature of the contents of the tanks and thereby kept down the evaporation losses. The saving effected was 86.5% of the evaporation of 55 to 60 degrees distillate which occurred from the wooden roofed steel tanks.

These water seals were also tried out on some small receiving tanks. Reports on 100 barrel tanks showed a reduction of the evaporation loss to an average of 1.32% of the volume, compared to 14.68% from similar small tanks having plain roofs. The gravity loss was reduced from an average of 4.8 degrees Baume to an average of 0.13 degree.

Refineries were also experimenting by burying the steel tanks in the ground. But soil corrosion resulted in their rapid deterioration with consequent many small leaks which were difficult to detect and expensive to repair. Tile was also used to enclose tanks and was said to reduce evaporation losses from 4 to 6%. Small reinforced concrete tanks holding about 1,500 barrels each were also buried in the ground and prevented some evaporation losses.

A more thorough study of evaporation losses was made by the United States Bureau of Mines for the year 1919. The report which was published in 1922 stated that in one stage only of handling crude oil, that is, during the first few days that the crude oil was stored on the leases, the volume of gasoline which evaporated in the Mid-Continent field alone, was equal to 3.33% of the entire gasoline production of the United States and that it was over one-third of the entire natural or casinghead gasoline produced.

It was found that some of the large companies had tried to determine their evaporation losses from crude oil and had reduced them to some extent and that the progressive

refining companies had done much to prevent the evaporation of gasoline. The oil companies were anxious to and did cooperate with the Bureau of Mines, not only in the determination of the evaporation losses but in finding means for their prevention.

Evaporation losses not only result in a lesser volume of crude, but as the lighter or gasoline fractions are the principal ones to vaporize, they cause a decrease in the gravity of the oil and the amount of gasoline which can be extracted from it. Naturally, the decrease in the gravity depends on the nature of the crude. It is small for heavy oil compared to that for the lighter crudes.

Important evaporation losses occurred from the flow tanks, in the filling of the lease tanks, from the oil stored on the leases, in the pipe line gathering tanks, during transportation and at tank farms and refineries. Over 50% of the loss took place before the oil reached the pipe lines.

The greatest evaporation loss per unit of time was found to come from the overhead filling of receiving tanks on the producing leases. It amounted to from 1 to 2% of the volume within a few hours. A substantial saving was being made on some oil leases through filling these tanks from the bottom as the oil was not then exposed to the air except at the top of the liquid. Large losses occurred when the small tanks were not protected from the sun's rays or from the free circulation of air.

The least evaporation loss per unit of time took place when the oil was stored in the large 35,000 and 55,000 barrel tanks at the tank farms and refineries. Losses there ranged between 0.7 and 3.0% a year, depending on the gravity of the oil and the length of time that it had been in storage. If stored long enough, there would be no further loss.

Conclusions were summarized for the Mid-Continent field as shown in the next table.

TABLE 40.

APPORTIONMENT OF THE EVAPORATION LOSSES SUSTAINED BY MID-CONTINENT CRUDE FROM THE WELL TO THE REFINERY.

Place of Loss	Per Cent. of Volume of Crude Evaporated: Summer	Autumn and Spring	Winter	Average
Flow tank	1.2%	1.0%	0.8%	1.0%
Filling lease tanks	1.2	1.0	.8	1.0
Lease storage	1.8	1.4	1.2	1.5
Pipe line gathering tanks..	1.3	.9	.8	1.0
During transportation	1.2	.9	.8	1.0
Tank farms	.9	.7	.6	.7
Total	7.6	5.9	5.0	6.2

The crude production of the Mid-Continent field in 1919 was reported at 193,147,000 barrels. As 3.5% of the evaporation losses had taken place before the oil was measured, the actual production was around 200,152,000 barrels. So that 7,005,000 barrels of crude were lost before it reached the pipe lines. Then followed the estimated 2.7% loss which meant 5,215,000 barrels, making the total estimated loss 12,220,000 barrels.

Considered as crude oil of an average value of $2.16 a barrel at the wells, the figures estimated by the U. S. Geological Survey for Mid-Continent oil for 1919 in its 1922 report, the loss through evaporation in this one field alone was $26,495,200. But the evaporated fractions of the oil were practically all gasoline, which at the then average price of around 22 cents a gallon, would have had a value of $112,-912,800.

As the Mid-Continent field produced only 51.0% of the total production of the United States, the total losses might be considered approximately twice that amount. But that would be an overestimate, as the evaporation losses from the California and Gulf Coast fields would not have been nearly as large as from the high gravity Mid-Continent one.

In any event, the losses were enormous.

The general conclusions drawn by the Bureau of Mines were:

Evaporation during storage and handling causes one of the largest losses of crude petroleum between the well and the refinery;

From two-thirds to four-fifths of the evaporation loss may be eliminated by protecting oil from free contact with air. This protection will pay for itself in a short time;

The percentage of the original *value* lost by evaporation is two or three times the percentage of the original *volume* lost, because the fraction that escapes from the crude oil is the best gasoline and its value per unit is two or three times that of crude;

The maximum prevention of evaporation involves keeping the mixture of air and vapor above the oil at rest and as near a constant temperature, whether high or low, as possible. For example, if the mixture of air and vapor above the oil does not move, very little more evaporation will take place at 115 degrees Fahrenheit than at 32 degrees because the mixture will soon become saturated and then evaporation will cease;

The major part of the evaporation loss, when the most valuable products escape, takes place on the lease when the oil is still fresh;

Oil is liable to evaporation loss, even after it leaves the lease;

Dehydration in open steaming plants is the most flagrant example of the neglect to prevent evaporation losses. Such plants should be made air tight with valves for regulating pressures;

Overshot connections should never be used for filling a tank;

Even in winter, when atmospheric temperatures are low,

oil in exposed lease tanks will lose more than one-half of what it would lose during similar storage in summer;

Oil at the surface of 55,000 barrel tanks, where evaporation takes place, is subjected during a part of the day to temperatures much higher than the average temperature of all the oil in the tank. In summer, these surface temperatures rise above 100 degrees Fahrenheit. Evidently in such storage the loss by evaporation must be large;

For one who handles crude, evaporation is almost as insistent as it is for the refiner who handles the gasoline obtained from the crude, because gasoline in the natural crude will evaporate approximately one-half as rapidly as it will after being distilled and stored as pure gasoline;

The more volatile the gasoline contained in a crude, the more nearly will the rate of evaporation of the crude approach the rate of evaporation of the gasoline (stored in the pure state) distilled from the crude, evaporating conditions of both being the same;

The increasing demand for crude oil and gasoline is making this problem more and more insistent. In future, it may be considered as illegal to waste oil brought to the surface, as it is now considered illegal to waste it underground;

So many conditions vary the rate of evaporation that to cover them all would require an almost unlimited amount of work. Each operator of a lease or pipe line should attack and solve his own problems.

There were no particular engineering problems involved in preventing evaporation losses to a great extent. The principal ones were the amount of capital required to install the proper tanks, gas collecting systems and other apparatus for the prevention of the losses and whether or not the savings effected would justify the expenditure. This was no problem for the large progressive companies, as they

had already done much to prevent evaporation and they have always been ready to spend millions to prevent waste of this natural resource. But to the small producers, and there were many thousands of them, the financial problem was the main one to overcome. The suggestions made by the Bureau of Mines were in accord with much of the work which had been done by the large progressive companies.

The Bureau of Mines advised that the most practicable way of reducing evaporation loss was to make the tops of all tanks gas tight and to keep them under a slight pressure, regulated by automatic valves; to do away with all overshot connections, and to connect all tanks with the casinghead or natural gasoline plant, if one were already installed. Practically 100% of the evaporation loss could be saved if such connection were made and if the necessary gasoline plants were built.

Studies of the effect of different colored paints on tanks were afterwards made with the result shown in the next tables.

TABLE 41.

RESULTS OF EVAPORATION TESTS ON A 55,000-BARREL CRUDE OIL STORAGE TANK.

Color of Tank	Evaporation Loss in One Year		Gravity Loss,
	Barrels	Per Cent.	Degree Baume
Black	649	1.24%	0.6
Red	609	1.14	0.5
Gray	547	0.99	0.3
Aluminum	447	0.83	0.2

TABLE 42.

RISE IN TEMPERATURE AND PERCENTAGE LOSS BY VOLATILIZATION IN SMALL TANKS FILLED TWO-THIRDS WITH NAPTHA AND EXPOSED TO THE SUN FOR TWO HOURS.

Color of Tank	Temperature of Naptha, Degrees F.	Percentage of Loss
Black	111	9%
Bright red	109	8
Dark red	108	8
Dark green	108	8
Battleship gray	106	6
Tan	104	5
Red primer, white top coat	102	5
Cream or pale blue	102	5
White	100	4

These and other tests show the economic value of light colors over dark ones for the painting of tanks.

The most successful way to eliminate practically all evaporation losses is by the installation of gas collecting systems through which all tanks are connected with natural gasoline plants. All vapors are thereby conducted to these plants and the gasoline recovered from them. These systems have been installed by the progressive companies.

But there are some fields in which there are not sufficient gas and waste vapors to warrant the erection of a natural gasoline plant, although such producing fields are becoming fewer and fewer as time goes on.

In all fields, vapor tight tanks have proved so effective in reducing evaporation losses that nearly all oil operators are using them. The filling loss of lease tanks so equipped have been reduced from the former figures of around 1.0% of the volume of the crude, to an average of between 0.1 and 0.2%, a reduction of from 80 to 90% of these heretofore important losses.

What are known as breathing losses occur from some vapor tight tanks. They are caused by atmospheric variations. During the day when the temperature rises, the gasoline saturated vapors in the tanks expand and are vented out into the air through control valves. At night, owing to the decrease in the temperature, the vapors contract and fresh air is sucked into the tanks. This air becomes saturated with the gasoline vapors. It is forced out the next day when the vapors expand and these gasoline fractions are emitted into the air.

On some leases collapsible breather bags have been installed which fill up with the vapors from the tanks during the day and return them in the nighttime. In this way no fresh air is admitted into the tanks and there are no evaporation losses.

Breathing losses are also reduced in three other ways: operating the tanks under pressure, using light colored paints on the tanks and by the erection of wooden houses to protect the tanks from the rays of the sun and from the wind.

The breathing loss from a vapor tight tank that is filled and emptied each day is almost negligible, even when added to the average filling loss of from 0.1 to 0.2%. These two losses combined in such tanks are not sufficient to affect the value or gravity of the crude materially. But when the production conditions are such that it takes several days to fill the lease tanks, these combined losses are such as to warrant the use of means for their prevention.

If sufficient pressure is used, the vapors will be held in the tank. The amount of pressure which can now be used is many times that formerly employed. Bolted tanks operate under pressures up to 18 to 20 ounces and many producers have installed riveted or welded tanks which are operated under pressures up to five pounds. Local condi-

tions, however, sometimes limit the amount of pressure which can be so used on lease storage and flow tanks.

Tests have demonstrated that a vapor tight tank equipped with a pressure relief valve opening at only two ounces of pressure, will show a loss from filling and breathing of only from 1.40 to 2.80% of volume over a period of 36 days according to the season, and a gravity loss of from 0.55 to 1.10 degrees A. P. I. Thirty-six days are several times the number during which the crude oil is held on the leases and these losses show a very substantial reduction for the former ones of from 4.7 to 9.8% for the same period.

Where such tanks are operated under a pressure of only 16 ounces, the loss in volume for this same length of time varied from 0.59 to 1.18% while the gravity loss was from 0.3 to 0.6 degree. This increased pressure saves approximately 60% of the evaporation losses which occur under 2 ounce pressures. As the pressure is increased in tanks which will stand up under them, the losses are further reduced.

Other tests show that tanks covered with aluminum paint reduce the average variation in the temperature of the vapor by approximately 13 degrees F. from that of red painted tanks and that properly housed tanks give a further reduction of 9 degrees. The latter installation must be very carefully made as the wooden cover may act as a flue and increase the circulation of air in the vapor space above the oil, where the tanks are not kept vapor tight. Fire risks are also augmented in wood housing when the boards become saturated with oil.

Very good results are being obtained in the reduction of evaporation from vapor tight tanks which are not connected with gasoline recovery systems, through the combination of suitable pressure and light colored paint. Other improvements in tanks have been made by the installation

of floating and breather roofs which are reported to give satisfactory results.

The effect of the conservation of gasoline through the large decrease in evaporation losses is reflected in the increasing percentage of straight run gasoline recovered at the refineries during the past years shown in Table 19 and by the much greater production of natural gasoline which will be hereafter discussed. The decrease in these losses has resulted in an important conservation of our natural resource, petroleum. Credit must be given to oil operators and the important cooperation which has taken place between them and the Federal Government.

Refinery Improvements and Progress.

Evaporation losses from crude oil were the concern of thousands of small producers and a few large ones. Consequently the progress made in the prevention of such losses was not nearly as rapid as that of the refiners, who comprise only a few hundred units. Furthermore, the evaporation of the gasoline fractions from crude oil was less than one-half such evaporation losses from finished gasoline, so that the loss to the refining companies was much greater than to the producers.

The reduction of gasoline evaporation was most vital to the refiners and the problems involved were considered by them years before they were brought to the attention of oil producers, both because of the high losses of the finished product and for the reason that these losses were sustained by a comparatively few companies and not distributed among many operators and others in the various branches of the oil industry.

Refiners of crude oil made efforts to solve the evaporation problem of gasoline long prior to 1915, first by installing wooden roofs covered with paper and sheet iron on the storage tanks and then by the development of vapor tight steel roofs.

A comparison of the losses of refined gasoline from these two types of roofs is shown in the next table.

TABLE 43.

Evaporation Losses of Stored Gasoline at a Port Arthur Refinery in 1915 from Tanks Having One Vent for Leading the Escaping Gas or Vapor Outside of the Fire Levee.

	From Steel Tanks Covered by Wooden Roofs	From Steel Tanks Covered by Steel Roofs	Percentage of Reduction by the Use of the Steel Roofs
Gravity of gasoline when stored	55.9° B.	54.7° B.	
Gravity at end of test	55.2° B.	54.6° B.	
Loss of gravity	0.7° B.	0.1° B.	85.7%
Length of test	41 days	48 days	
Average gravity loss a day	0.017° B.	0.002° B.	88.2%
Loss of volume during test	3.39%	0.687%	
Average loss a day.......	0.08268%	0.01431%	82.7%
Annual rate of loss	30.171%	5.223%	82.7%

Comparative Losses of Stored Distillate of 55-60° Baume in 1915 from Available Data.

	From Wooden Roof Tank	From All Steel Tank	Percentage of Decrease With All Steel Tank
Yearly rate	27.8%	4.36%	84.3%

Variation in the evaporation loss which takes place when the steel roofs are of different degrees of vapor tightness is illustrated in the next tables.

TABLE 44.

EVAPORATION LOSS OF STORED GASOLINE IN 1925.

	10,000-Barrel Tank With Uncaulked Roof in Bad Condition, Painted Dark Gray	25,000-Barrel Tank Not Wholly Vapor Tight, Painted White	Percentage of Reduction in Loss
Gravity of gasoline:			
At beginning of test	58.9°	60.2°	
At end of test	57.4	58.7	
Loss of gravity:			
Total	1.5	1.5	
Average daily	0.024	0.024	
Percentage of evaporation loss:			
In 23 days	1.64%	0.55%	66.5%
In 39 days	2.66	1.08	59.4
In 54 days	3.60	1.34	62.8
In 63 days	4.25	1.73	59.3
Average daily loss	0.06746	0.02746	59.3
Annual rate of loss	24.6229	10.0229	59.3

TABLE 45.

Summary of the 1925 Tests of the Bureau of Mines of Gasoline Evaporation Losses and Losses of Gravity.

Tank	Condition of Tank Roofs	Length of Test in Days	Yearly Rate of Losses Gravity	Yearly Rate of Losses Evaporation
No. 1 10,000 bbls. 58.9° gravity	Bad condition and painted gray ...	63	8.760°	24.6229%
No. 2 10,000 bbls. 69.3° gravity	In somewhat better condition	109	12.045	21.7659
No. 3 10,000 bbls. 73.9° gravity	In about the same condition	88	11.614	31.9373
No. 4 25,000 bbls. 60.2° gravity	Not vapor tight but painted white ..	63	8.760	10.0229
No. 5 25,000 bbls. 60.0° gravity	In better condition than No. 4 but painted gray ...	99	4.056	10.1835
No. 6 40,000 bbls. 59.8° gravity	In still better condition. Painted light gray	120	1.217	4.6537
No. 7 66,000 bbls. 54-56° gravity	Welded roof painted white	30	not given	2.6767

These tanks were in the same locality and the tests were begun at about the same time, so that the average atmospheric conditions were somewhat similar. But exact conclusions cannot be drawn from this comparison owing to the difference in the physical conditions of the tanks and in the gravity of the gasoline.

The tests indicate the enormous loss of gasoline which resulted in the storage in other than vapor tight tanks. Substantial progress had been made by the refiners in the installation of tanks which reduced these losses by a considerable extent, with the resultant conservation of this important petroleum product, gasoline.

Certain other factors were also shown by these tests, especially the effect of the amount of vapor space above the gasoline. Tanks 1 and 2 were covered with globe or umbrella roofs and the vapor space was approximately 9,625 cubic feet in each tank, or 4.9 cubic feet for each square foot of evaporation surface of the gasoline. In the larger tanks 4 and 5, this vapor space was only 11,256 cubic feet, or 2.4 cubic feet for each square foot of evaporation surface. So it appears that the substantial reduction in the annual rate of evaporation loss depended to some extent in decreasing the vapor space in the tanks.

Figured on the percentages of loss shown and the average of 38,820,000 barrels of gasoline in storage in 1926, the evaporation losses would have been as follows:

TABLE 46.

ESTIMATED EVAPORATION LOSSES OF STORED GASOLINE IN 1926, IF ALL TANKS HAD BEEN CONSTRUCTED IN THE MANNER SHOWN.

	Barrels of Gasoline	Value at 11.9 Cents a Gallon or $5 a Barrel
With wooden roofs, see Table 43	11,712,382	$58,561,910
" steel " " " "	2,027,569	10,137,845
Similar to No. 1 tank, Table 45	9,558,610	47,793,050
" " " 6 " " "	1,806,566	9,032,830
" " " 7 " " "	1,039,095	5,195,475

Further improvements in vapor tight roofs have been made, which reduce evaporation losses of stored gasoline

to around 2.0% a year of volume in standing storage. Floating roofs have been introduced, which are said to reduce this loss to less than 1.0% annually.

The replacement of wooden roofs by steel ones has also done much to reduce the fire and accident hazard. Wooden roofs act as condensers for electricity and are much more likely to be struck by lightning and be ignited by static electricity than steel ones.

But these evaporation losses from the storage of finished gasoline were not the only ones suffered by refiners. Further losses occurred through the formation of fixed gases in straight refining which contained 1.0% or so of gasoline which could not be liquefied in the refinery condensers; from the run down tanks into which the gasoline is run from the condensers (these losses were reported in 1925 to average not less than 1.8% of the gasoline made); from the treatment of gasoline by acid for the removal of impurities through former air agitation, which losses exceeded 0.5% of volume; and from filling tank cars through the top, which losses have run in excess of 2.0%. Taken all in all, there were former large wastes of gasoline, both in its making and in its storage.

Practically all this waste of every description is now prevented at the most modern refineries. They have installed gas recovery or collecting systems, which gather the evaporated vapors from all tanks, collect all fixed gases and vapors from stills and all other gases which are afterwards run through natural gasoline plants which extract the gasoline. Reports from such refineries show that from 6 to 9% of their total gasoline production comes from these natural gasoline plants, gasoline which had been formerly wasted.

Many millions of dollars have been spent by the modern refiners in installing closed continuous pipe stills, closed continuous gasoline treating tanks, modern storage and run

down tanks and gas collecting systems and natural gasoline plants.

These improvements not only conserve practically all the very high fractions of gasoline which were formerly lost at the refineries but the fixed or uncondensible gases are thereby recovered and used as fuel. This utilization results in the conservation of a large amount of fuel oil and coal for other consumers. Furthermore, these improvements have reduced the accident and fire hazards very materially, and they prevent the pollution of the air by the former wasted gases.

An important progressive step in straight refining has been made through the installation of heat exchangers, whereby many of the heat units formerly lost are now utilized. Attention has heretofore been called to the heat exchangers which have been installed in the cracking plants, and approximately the same conservation has been effected through their use in the refineries.

During the past few years, the large refining companies have been constantly increasing these installations for the prevention of the waste of heat units in as far as it can be done consistent with the desired separation of the gasoline, kerosene and other fractions of crude oil.

Most of this heat is recovered by passing the fresh crude oil through coils in the hot vapors, but a part is obtained from the hot liquids. This fresh crude acts as the condensing medium for the liquefication of these vapors into the various refinery products, and it takes the place of air and a large amount of water which were formerly used for cooling and condensing purposes.

Through these heat exchangers, the temperature of the crude oil is raised to between 400 and 500 degrees Fahrenheit without the use of any primary fuel, and a substantial part of the gasoline is distilled from the crude oil before any heat from the furnaces is required.

Pipe stills and the fractionating bubble towers have also revolutionized refinery practice by increasing the furnace efficiency and decreasing a substantial part of the former rerunning of the intermediate refinery products. In some refineries, the fuel consumption under stills has been cut in half. A great decrease in the heat requirements to produce steam has also been effected. It formerly required about 100 pounds of steam, or even more, per barrel of crude refined, but this has been reduced to between 10 and 20 pounds at some plants. The replacement of the pipe stills for the old shell ones formerly used has also decreased labor costs, as the number of men now employed in the still crews are from 20 to 30% of those formerly used in many cases.

The installation of pipe stills and the utilization of the formerly wasted heat units have also resulted in the conservation of the gasoline contained in much of the heavy oils. Most of the heavy oil production is now refined instead of being used, as was formerly done for fuel, without being refined. While the production of heavy oils has increased to several times that of 1916, yet the consumption of heavy crude oil for fuel purposes is now about 40% of that for that year. The refining of these heavy crudes was not commercially practical under the methods then in use. Whatever gasoline was contained in them was an absolute waste, except as it contributed to the heating qualities of the fuel oil. In many cases, this heavy crude was weathered, and the gasoline thereby evaporated into the air in order to increase the flash point of the fuel oil to the required specification.

The refining of these heavy oils, therefore, now constitutes the conservation of their recoverable gasoline contents. But their refining has decreased the average percentage of the total recovery of gasoline from all crudes in the United States, and particularly in California, where

the largest amount of heavy crudes is processed. However, such refining has added substantial quantities of gasoline to our national production.

Refining companies must be credited further with the development of methods for the refining of the high sulphur crudes, also known as sour oils, of which the production has substantially increased during the past few years. The principal oils of this nature are the Panhandle and West Texas crudes, and they could not have been refined through the methods in use some years ago.

While their refining is not in one sense a conservation of crude oil, as they can be weathered and used for fuel, yet it does recover their gasoline content and adds so much to the gasoline production. It further results in the highest present utilization of these crudes through obtaining the gasoline and producing a fuel oil of a better quality.

New manufacturing problems have come up in the refining of these sour crudes, and some of them have not been fully solved. The refining cost will probably always be high and the yields of the lighter products comparatively low, compared to the results from the Mid-Continent crudes, but the gasoline produced is reported to have high anti-knock values.

These Panhandle and West Texas crudes contain hydrogen sulphide, which sets up a corrosive action which it is difficult to counteract, and large quantities of calcium and magnesium chlorides, from which hydrochloric acid is generated in refining. This hydrogen sulphide attacks the iron of the refinery equipment and forms iron sulphide, which oxidizes when exposed to the air, thereby producing heat which is sufficient to make it red hot with the resultant fire risks.

This sour crude is treated in a number of ways. It may be pre-treated with caustic to remove or neutralize the hydrogen sulphide. But that takes out the free hydrogen

sulphide only, which is a small part of the potential hydrogen sulphide in this crude oil.

During refining, the neutralization of its corrosive features can be done by injecting caustic or soda into the stills, but this may result in hot spots at the bottom of the still and cause fires or explosions. Ammonia is also used as a neutralizing agent.

When this sour crude is topped for gasoline only, it is sometimes possible to run the stills dry. This prevents the formation of hydrochloric acid, owing to the lack of sufficient water to unite with the chlorides. These chlorides can also be eliminated through filtering the crude at a somewhat higher temperature than normal, which also removes the water from the crude oil.

None of these methods removes or decreases the amount of hydrogen sulphides evolved during the distillation process, and the greatest care must be used to prevent fires when the refinery equipment is opened up. This is accomplished by keeping the iron sulphide wet or by replacing the air in the stills with steam until it is possible to scrape out the iron sulphide.

Further precautions must be taken in the run-down tanks, on which the iron sulphides collect very rapidly where sour distillates are run. Danger from hydrogen sulphide is also prevented by using vapor tight tankage under slight pressure or vacuum connected with the gas recovery systems, as oxygen is thereby excluded from the tanks, and iron sulphide cannot be formed.

Reduction of Refinery Losses.

THERE WILL always be some unpreventable losses in the refining of crude oil as the contained water, sulphur, sulphur compounds, gum-forming constituents and other impurities must be removed. The net result of the reduction of refinery losses through the improvements made in the apparatus and equipment and in refinery practice is shown in the next table.

TABLE 47.

PERCENTAGE OF REFINERY LOSSES TO CRUDE OIL PROCESSED.

Year	Percentage	Year	Percentage	Year	Percentage
1918	4.47%	1921	4.41%	1925	3.06%
1919	4.43	1922	3.71	1926	3.46
1920	4.32	1923	3.26	1927	3.42
		1924	3.04		

While this is a substantial decrease, it does not represent the savings actually effected. During the past few years, there has been a large increase in the amount of crude oil which is completely refined, and a very large increase in the gas oil and other partly refined crudes which have been reprocessed through the cracking plants. Losses from the complete refining of crude and the additional ones resulting from cracking are much larger than those from topping and skimming.

It is probable that the improvements in apparatus and equipment and in refinery practice have reduced actual

losses by 50% from those of 1918, instead of the 23.5% decrease shown. These refinery losses averaged 77,600 barrels a day of crude oil in 1927. At the 1918 rate, they would have been 101,400 barrels a day, so that 23,800 barrels a day of crude oil have been conserved through the reduction of refinery losses, or 8,687,000 barrels a year. The actual conservation is probably at least 50,000 barrels a day, or 18,250,000 a year, if it were not for the improvements in refineries and in refinery practice since 1918.

Natural Gasoline Plants.

THE PRODUCTION of natural gasoline is now running over 113,000 barrels a day. That is equal to the amount of gasoline produced by the refineries from 660,000 barrels of crude oil a day at the 1914 percentage of recovery, and from 475,000 barrels daily of crude oil at the 1927 rate. See Table 19. The natural gasoline now being produced can be considered to be conserving either 240,900,000, or 173,375,000 barrels of crude oil a year, according to the basis on which one desires to figure.

Indeed, the conservation exceeds these figures, as natural gasoline has a gravity of 20 degrees or so higher than the average straight run. Its production thus permits the output by refining and also by cracking of a large amount of low grade or low gravity gasoline or naptha, which is utilized in the making of a gasoline or motor fuel of the required specifications through blending with this high gravity natural gasoline.

The present daily average production of natural gasoline is over 40 times that of 1914, when it amounted to only 2,776 barrels a day. This remarkable increase in 13 years is due to four causes, the increased number and capacity of natural gasoline plants, their greater efficiency, the present recovery through them of gasoline from dry or semi-dry natural gas, and the important reduction in the evaporation losses from crude oil, effected partly through the collection of the formerly wasted vapors laden with the gasoline which is now recovered in these plants.

While the natural or casinghead gasoline industry is a comparatively recent development, it was started some years before that of cracked gasoline. Natural gasoline was

produced on a small scale in 1900 by a few oil producers in West Virginia and Pennsylvania. Gas transmission lines had been showing considerable quantities of gasoline, and devices were installed to catch it. Coils were placed in old boilers and tanks which were filled with running water for the condensation and accumulation of this gasoline. Although very volatile, the raw product was shipped to the market in its original form. Blending with the comparatively low gravity napthas was not begun until later.

In 1904, the first plant was built, but it did not become a commercial industry until 1910. The method used was that of compression and cooling. Production through absorption did not come into commercial use until 1913. Since then, absorption plants have largely replaced the compression ones, partly because the products are more stable and command a higher price.

The compression and cooling plants were built to extract gasoline out of the rich casinghead gas, which produced from 4 to 6 gallons of gasoline per thousand cubic feet. This casinghead gas came from the oil sand and arose between the casing and the tubing in the oil wells. The term was afterwards broadened to apply to any gas rising with the oil in the tubing or flow lines and to the vapors which separated from crude oil in traps or flow tanks.

It was the Eastern custom to collect only that gas which came up with the oil in the tubing or the light gasoline fractions given off in the flow or storage tanks. Oklahoma oil operators gathered the gas at the casinghead and sometimes from the flow lines and tanks. In California, oil and gas were run into specially built tanks or traps which allowed the gas to separate from the oil either above or below atmospheric pressures. The gas was then collected and run through the casinghead gasoline plants.

Until 1911, most of these plants consisted of the simplest form of gas pumps, single stage compressors and cooling

coils of a capacity of not more than 200,000 to 300,000 cubic feet of gas a day, and they were operated on this rich casinghead gas. By 1916, plants were installed which could treat from 6,000,000 to 9,000,000 cubic feet of gas daily and gas yielding as low as one gallon of gasoline per 1,000 cubic feet.

Pressures of 250 to 300 pounds to the square inch were used in two stages of compression, and elaborate systems of cooling the gas with water before compression and after each stage were installed. In some plants, the gas was further cooled by expanding the dry gas which had already been treated through the cylinders of an expansion engine and using the cold expanded gas to cool the high pressure gas from the water cooled coils. Temperatures as low as 0 degrees Fahrenheit were often obtained, which caused the liquefaction of nearly all the condensible fractions which were commercially valuable for gasoline.

These compression and condensation plants were considered to have established a large and lucrative industry in this country in 1915, when they produced about 1,556,300 barrels of gasoline of a value of $5,150,823. They were then somewhat of a factor in the production of commercial gasoline or motor fuel, as the gasoline was blended with the low gravity naptha, which thus became utilizable for the production of motor fuel.

The treated casinghead gas and the gasoline recovered represented natural gas and gasoline which were formerly wasted. Their recovery was considered "a distinct and important step in the utilization of the natural gas produced in this country" in the report of the Bureau of Mines issued in 1918.

But if the production of 1,556,300 barrels of natural gasoline in 1915 was "an important step in the utilization of natural gas," how must the production of 38,667,000 barrels in 1927, or nearly 25 times that of 1915, be considered?

Natural gasoline recovered in these compression plants comprised practically all the natural gasoline produced prior to 1916. The statistics of the industry as far as available up to 1916 are shown in the next table.

TABLE 48.

NATURAL GASOLINE PRODUCTION IN THE UNITED STATES AND OTHER STATISTICS.

Year	Number of of Plants	Barrels Produced	Value of Production
1911	176	176,800	$531,704
1912	250	287,600	1,157,476
1913	341	572,900	2,458,443
1914	386	1,015,500	3,105,909
1915	414	1,556,300	5,150,823

Year	Natural Gas Treated in 1,000 Cubic Feet	Average Yield of Gasoline Per 1,000 Cubic Feet
1911	2,476,000	3.00 gallons
1912	4,688,000	2.60 "
1913	9,889,000	2.43 "
1914	16,895,000	2.43 "
1915	24,064,000	2.57 "

AVERAGE YEARLY PRODUCTION AND VALUE FOR EACH PLANT.

Year	Barrels of Gasoline	Value	Average *Daily* Amount of Gas Treated
1911	1,005	$3,021	38,500 cubic feet
1912	1,150	4,630	51,400 " "
1913	1,680	7,210	79,500 " "
1914	2,630	8,046	119,600 " "
1915	3,760	12,441	159,300 " "

Only rich casinghead gas, or wet natural gas which contained over one gallon of gasoline per 1,000 cubic feet, could be treated economically by compression and condensation. This prevented the utilization or recovery of the gasoline

contained in not only a large amount of casinghead gas of a lower gasoline content than one gallon per 1,000 cubic feet but also that contained in the very large quantity of natural gas which was produced in this country and used for fuel and lighting purposes.

In 1914, the 16,895,000,000 cubic feet of casinghead gas which were treated in the natural gasoline plants amounted to only 2.8% of the 591,866,733,000 cubic feet of so-called dry natural gas which was produced and used for fuel and lighting purposes. Any gasoline that could have been extracted from this natural gas was therefore wasted, as it did not increase the fuel or lighting value of the gas to any appreciable extent. The burning of this unextracted gasoline, therefore, constituted a substantial economic loss or waste.

This dry natural gas was once in contact with crude oil or was formed by the same processes which produced the oil. In many cases, it consists of the light hydrocarbons which escaped from the sands containing oil and gas and which carried with it some gasoline vapors.

In pumping this natural gas through the pipe lines to the consuming centers, it was found that considerable gasoline was deposited at the cooling stations after leaving the compressors. This gasoline was a constant source of expense and annoyance, as it softened and decomposed the rubber rings in the pipe couplings and caused blowouts, leaks and a resultant waste of gas.

Any method for its removal would not only conserve the gasoline for the users of motor fuel but it would decrease the waste of natural gas through leakage, prolong the life of the pipe line couplings, result in less pipe line troubles, increase the safety of operations and give a greater uniformity in the distribution of natural gas, especially in the winter.

The compression plants could remove nearly all the gasoline fractions from rich casinghead gas. But this was

not desirable, as some of them were of such high volatility that they could not be retained in the liquid gasoline at normal pressure and temperatures, and they made it unfit for use in the raw state. Therefore, these very light fractions had to be evaporated out by weathering, and they carried with them some of the heavier and useful parts.

Casinghead and natural gas contain some very highly volatile and unstable hydrocarbons which have vapor pressures from 50 to 150 pounds or more at 100 degrees Fahrenheit and vaporize at very low temperatures. They comprised the "wild" gasoline constituents which cannot be retained under normal temperatures and pressures.

Practically all natural gas contains the gasoline hydrocarbons of medium gravity which have vapor pressures up to 12 pounds to the square inch at 100 degrees Fahrenheit. They are the important and usable fractions of natural gasoline.

The gasoline produced by compression and condensation was not a desirable motor fuel. It was very volatile and somewhat dangerous to handle as fumes were readily formed. The heat units per volume were comparatively low, and less power per gallon was developed than by the heavier fractions of gasoline. A larger number of gallons was required to develop the same power. While it gave a quick, sharp explosion in a motor cylinder, it lacked the push after the explosion took place. These qualities are the same as those of the very light fractions of gasoline obtained through the refining of crude oil, and both light products require the addition of the less volatile heavier fractions of gasoline in order to form an economical and convenient motor fuel.

Furthermore, the regulations concerning shipments of petroleum products and liquefied natural gas over the railroads did not allow their shipment in standard tank cars when their vapor pressure was over 10 pounds per square

inch, or in specially constructed insulated cars when the vapor tension exceeded 15 pounds.

Many of the compression plants produced a natural gasoline with a vapor pressure of 30 pounds or more as it came from the accumulator tanks, so it had to be weathered or blended in order to bring it within the shipping rules and for the improvement of the quality of the product.

In some compression plants, the yield of natural gasoline was 4.98 gallons per 1,000 cubic feet of casinghead gas, but its vapor tension exceeded 22 pounds to the square inch and its gravity was over 91 degrees Baume. This product was not usable and it could not be shipped. It had to be weathered, during which it lost 2.51 gallons of the very light products, and its vapor tension was reduced to 13 pounds, a weathering loss of 50.4%. Further weathering in order to reduce its vapor pressure to 9 pounds resulted in an additional loss of 15% of the reduced volume, making the total weathering loss 57.9%. The net result was the recovery of a usable natural gasoline of 2.1 gallons per 1,000 cubic feet of gas.

In Oklahoma, the weathering loss varied from 10 to 20%, and the total loss ran as high as 42%, depending on the gravity of the raw product and its vapor tension. Often heating with steam was necessary before the gasoline could be loaded into tank cars in order to bring the vapor pressure within the limits allowed by the railroads, especially in cold weather, when the weathering did not bring the tension down to the desired point.

In 1918, the losses in the Mid-Continent field were summarized as shown in the next table.

TABLE 49.

SUMMARY OF LOSSES OF NATURAL GASOLINE IN THE MID-CONTINENT FIELD IN 1918.

Cause of Loss	Percentage of Volume
Weathering	5 to 20%
Transferring to Loading Stations	2 to 7
Loading in Tank Cars	1 to 5
Shipping in Standard Tank Cars	2 to 10
Total	10 to 42%

Compression plants which treated gas containing a large proportion of the very light gasoline fractions and in which very low temperatures and high pressures were used made very "wild" natural gasoline. They not only suffered the largest weathering loss but this product did not improve the reputation of natural gasoline as desirable for blending purposes.

Other compression plants which were not run under very high pressures and too low temperatures produced a natural gasoline of a gravity of 79 degrees Baume and a vapor pressure of about 5 pounds. It was shipped in tank cars, the total loss was not over 3%, and this gasoline contained practically all the desirable gasoline fractions of the casing-head or natural gas.

Investigations of the Bureau of Mines made in 1917 and of the oil industry prior to that time resulted in the conclusion that much of the natural gas which was used for fuel and lighting could be successfully treated and the gasoline extracted through the absorption method. It consists of forcing the gas through an oil which would absorb the gasoline and then distilling this gasoline from the oil; or in passing the gas through 50 to 55 degrees naptha and allowing it to be absorbed by the naptha. This increased the volume of the naptha and raised its gravity by 10 or so degrees.

It was also found to be impossible to extract all the gasoline out of the rich casinghead gas by compression and condensation unless excessive pressures and extremely low temperatures were used, which resulted in too wild a gasoline and that this method failed to give satisfaction when the gasoline contents were less than 1 gallon to 1,000 cubic feet of gas. Tests made in 1919 indicated that as much as 0.63 gallon of gasoline was left in 1,000 cubic feet of residual gas from the compression plants and that it averaged over 0.337 gallon.

When this residual gas was run through absorption plants, most of this gasoline was recovered. An average of only 0.10 gallon per 1,000 cubic feet of gas was left in the residual gas after it had passed through absorption naptha. In some cases, the unrecovered gasoline was less than 0.035 gallon. Absorption towers were then installed at many of the compression plants for the treatment of this residual gas.

The absorption process is more efficient than compression on the rich casinghead gas, and it is the only practical process for the recovery of gasoline from lean natural gas, vapors of refinery stills and the residual gas from compression plants. In 1913, the first commercial absorption plant was installed. It recovered 0.15 gallon of gasoline from lean natural gas and proved to be an economic and commercial success.

Since 1915, the expansion of the natural gasoline industry has been truly remarkable, as shown in the next tables.

TABLE 50.

NATURAL GASOLINE PRODUCTION, VALUE AND NUMBER OF PLANTS IN UNITED STATES SINCE 1915.

Year	Number of Plants	Barrels of Natural Gasoline Produced	Value of Product at the Plants
1916	596	2,464,000	$14,331,148
1917	886	5,188,000	40,189,000
1918	1,004	6,727,000	50,364,000
1919	1,191	8,370,000	64,197,000
1920	1,154	9,161,000	71,788,000
1921	1,058	10,713,000	61,815,000
1922	917	12,044,000	72,711,000
1923	1,067	19,434,000	77,268,000
1924	1,096	22,235,000	82,233,000
1925	1,081	26,845,000	120,383,000
1926	1,102	32,455,000	136,412,000
1927	not avail.	38,667,000	not available
		194,303,000	

TABLE 51.

NATURAL GAS TREATED AT NATURAL GASOLINE PLANTS IN THE UNITED STATES, WITH AVERAGE YIELD PER 1,000 CUBIC FEET AND PERCENTAGES OF GAS SO TREATED TO TOTAL NATURAL GAS CONSUMED.

Year	Natural Gas Treated in 1,000 Cubic Feet	Gallons of Gasoline Recovered Per 1,000 Cubic Feet	Percentage of Gas Treated to Total Consumption of Natural Gas
1911	2,476,000	3.00	0.5%
1912	4,688,000	2.60	0.9
1913	9,889,000	2.43	1.7
1914	16,895,000	2.43	2.8
1915	24,064,000	2.57	3.8
1916	208,705,023	0.50	27.7
1917	429,288,000	0.51	54.1
1918	449,109,000	0.63	62.3
1919	480,404,000	0.73	64.4
1920	496,431,000	0.78	62.2
1921	465,097,000	0.97	70.3
1922	545,139,000	0.93	71.5
1923	875,711,000	0.92	87.0
1924	1,016,276,000	0.92	89.0
1925	1,040,390,000	1.09	87.5
1926	1,206,300,000	1.13	91.9

In order to realize the great increase in the averages per plant, compare the figures in the next table with those in Table 48.

TABLE 52.

AVERAGE YEARLY PRODUCTION AND VALUE OF NATURAL GASOLINE AND AVERAGE DAILY AMOUNT OF NATURAL GAS TREATED PER PLANT.

Year	Average *Yearly* Production and Value: Production, Barrels	Average *Yearly* Production and Value: Value	Average *Daily* Amount of Natural Gas Treated in Cubic Feet
1916	4,140	$24,400	957,000
1917	5,860	45,400	1,327,000
1918	6,700	50,200	1,226,000
1919	7,030	53,900	1,105,000
1920	7,940	62,200	1,178,000
1921	10,130	58,400	1,204,000
1922	13,130	79,300	1,628,000
1923	18,210	72,420	2,249,000
1924	20,290	75,030	2,533,000
1925	24,830	111,360	2,635,000
1926	29,450	123,690	2,999,000

Since 1921, about 95% of the natural gasoline plants which have been erected have been absorption ones. A large number of the compression plants have been converted so that they can use the absorption process, and about three-fourths of all natural gasoline is produced by the latter method.

There has been some change in the type of plant erected during the past year or so. It has been found advantageous to install compression plants in some places. Where gas lifts are used for raising crude oil to the surface of the ground, at stations where the gas is injected into the earth in order to restore gas pressures in the oil sands and at booster stations which require heavy pressures, compression gasoline plants have been built. These heavy pressures are required for these other activities and are so utilized.

The next table shows the available data on compression and absorption plants and the increasing efficiency of the

latter. Where the total amount of treated natural gas appears to be larger than the totals shown in Table 51, some residual gas from the compression plants, which was also treated at the absorption ones, is included in the figures.

TABLE 53.

COMPRESSION AND ABSORPTION NATURAL GASOLINE PLANTS, WITH AMOUNT OF NATURAL GAS TREATED IN 1,000 CUBIC FEET AND YIELD OF NATURAL GASOLINE.

	Compression Plants			Absorption Plants		
Year	No.	Natural Gas Treated in 1,000 Cubic Feet	Yield in Gallons	No.	Natural Gas Treated in 1,000 Cubic Feet	Yield in Gallons
1916	550	36,713,415	2.31	46	171,991,608	0.11
1917	784	79,527,523	2.12	102	349,760,274	.14
1918	865	90,897,528	2.20	139	349,211,133	.18
1919	1,025	117,669,332	2.22	166	374,928,966	.24
1920	967	112,887,802	2.49	187	383,543,150	.27
1921	865	148,508,578	2.23	202	332,969,267	.35
1922	648	98,232,929	2.91	269	413,932,024	.44
1923	620	........*	...*	439	........*	...*
1924	639	........*	...*	445	........*	...*
1925	573	........*	...*	492	........*	...*
1926	493	........*	...*	579	........*	...*

*Not available.

By the absorption process, the heavier gasoline fractions in natural gas can be recovered first and the lighter or wild ones afterwards, if desired. The circulation of the absorbent oil can be limited to take out of the gas only those hydrocarbons which are desirable in the finished natural gasoline. This results in a more stable product which is not subject to the larger evaporation losses of compression gasoline. Progress has also been made in the manufacture of the latter, and its evaporation loss is not as large as formerly.

While a complete record of the losses of natural gasoline cannot be obtained, those for 1926 are estimated at ap-

proximately 10% of the volume made. That is a substantial reduction from former ones, and it has been decreased to around 5% at some of the best equipped plants.

Natural gasoline manufacturers have done their share towards the conservation of crude oil by supplying the lighter fractions of gasoline so that they could be blended with naptha and cracked gasoline in order to make a satisfactory motor product. But progress in the production of cracked gasoline by some processes has now reached a point where no blending is necessary. Modern refineries have also been recovering the formerly lost gasoline vapors through their gas collecting systems, and they extract this high gravity gasoline in their own natural gasoline plants. They have a fair supply for their own uses. This may result in some decrease in the demand for the gasoline made by natural gasoline manufacturers, and they may have further problems of their own to solve.

The hydrocarbons of natural gas vary somewhat in the different fields but are usually as follows:

TABLE 54.

CONSTITUENTS OF NATURAL GAS.

Methane, which vaporizes at				— 256.0	degrees F.
Ethane	"	"	"	— 119.4	" "
Propane	"	"	"	— 47.4	" "
Butane	"	"	"	+ 32.5	" "
Pentane	"	"	"	+ 97.7	" "
Hexane	"	"	"	+ 156.2	" "
Octane	"	"	"	+ 257.9	" "
Nonane	"	"	"	+ 302.9	" "

The first four are gases at ordinary temperatures and are not desirable constituents of commercial gasoline even if liquefied or absorbed in it. The last four are liquids at

normal temperatures and form the essential natural gasoline product.

In order to stabilize natural gasoline, various fractionating processes have been developed during the past few years through which the desired quantity of each of these hydrocarbons can be recovered from natural gas. This is the most advanced step in the natural gasoline industry since the development of absorption plants. It has made possible the utilization of large quantities of the separate constituents of natural gas for fuel purposes and for the manufacture of solvents and other products. It also points the way for the production of a natural gasoline which would make a satisfactory motor fuel without being blended with heavy napthas or cracked gasoline.

The most efficient natural gasoline plants can extract practically all the pentane, hexane, octane and nonane, which are the desirable fractions of natural gasoline, most of all the propane and butane and some ethane. The resultant product can be fractionated to produce a propane-butane mixture, which is put into containers under pressure and used as fuel. This liquid vaporizes immediately upon the release of the pressure and forms a gas of high heating value which burns with a colorless hot flame. It has been used successfully in place of acetylene for cutting steel in an oxygen torch.

There is no sulphur present in this mixture. An important demand may be developed in the pottery industry, for heating steel for certain purposes, in portable refrigerator equipment, for reducing ores in electric furnaces, as a base for cheap synthetic plastics and for other purposes.

After this propane-butane fraction is removed, practically pure butane can be fractionated out, which may be shipped in tank cars constructed for 150 pounds pressure per square inch. It vaporizes at 32.5 degrees Fahrenheit and forms 32½ cubic feet of gas per gallon and makes an

excellent fuel of a heat value of nearly 3,000 B. t. u.'s per cubic foot. It is used for the enrichment of manufactured gas, for fuel purposes and as an excellent, efficient and inexpensive refrigerant, probably far superior to ammonia.

During the past few years, considerable experimental work has been done in the manufacture of by-products from natural gas through controlled chlorination with the resultant production of certain chlorides, chloriform, hydrochloric acid and alcohols.

The dry gas resulting from natural gas after it has been processed through natural gasoline plants is more efficient than the original gas. It requires less air for combustion, burns with an intensively hot blue flame, produces no soot or grease on cooking utensils and does not give off the objectionable fumes associated with natural gas in its unrefined state.

Natural gasoline production has been increased through the development and use of portable natural gasoline plants. They save the gasoline content of the gas in new flush fields which was formerly wasted until permanent natural gasoline plants could be installed. The latter require a substantial investment, and their erection is usually delayed until sufficient information is obtained through the fields' development upon which to base the capacity of a permanent plant.

The oil industry has invested hundreds of millions of dollars in natural gasoline plants which have aided so much in the conservation of crude oil.

Reduction of Losses Through Corrosion and Water Troubles.

The conservation of crude oil effected during the past few years through the prevention or decrease to a substantial extent of the former losses resulting from corrosion and water troubles cannot be figured as there is no data available from which it can be determined.

Corrosion troubles affect the production, transportation and storage of crude oil as well as the refining branch of the industry. The resultant loss of crude oil has been principally in the production and pipe line ends, as the equipment affected and the losses are underground and not easily detected.

Entire oil and gas fields have been damaged or ruined by water that entered the productive sands through corroded tubing in wells. A large quantity of oil and gas is displaced and entrapped in the flooded sands and becomes irrecoverable. Some of the sands are also plugged by mineral salts, precipitated when different kinds of waters are mixed, and this prevents the further flow of the oil.

Fields have been prematurely abandoned through the corrosion of the equipment of oil and gas wells. It was estimated several years ago that in Kansas alone underground corrosion in the producing fields of that state caused losses of over $3,000,000 a year, resulting largely from the diminished production of oil where water flooded the wells through the corroded casing.

In some fields, the rapid deterioration and destruction of the metal equipment in oil and gas wells caused a waste of these natural resources, oil and gas, besides resulting in financial losses that had to be decreased or eliminated if operations were to be carried on successfully. The waste of

the equipment and its necessary replacement was a minor problem compared to the production troubles from corroded tubing and the serious waste of oil and gas.

Most corrosion troubles came through the rapid destruction of the metal equipment of oil and gas wells by the waters in certain fields which are intensively corrosive. They attacked the casing and the tubing in the wells and made it useless in a few years or even months. These underground waters were the principal cause of corrosion, which is primarily an electro-chemical process. It takes place when an electrical current passes from the metal into the water solution. All waters are not corrosive. The principal ones are the neutral saline waters, acid waters, those whose dissolved constituents yield or form acids and those containing magnesium chloride.

This corrosion resulted in holes being eaten in the casing and tubing of the wells, through which water and silt were admitted into the pay sands. Excessive amounts of water had to be pumped, emulsification of the oil, water and silt took place and salts were deposited in the wells. Oil and gas sands were flooded and drowned out in some cases. In other fields, the sand pores were plugged by the mineral deposited from the infiltrating water and the sands were sealed off by the fine silty products of corrosion which coated the walls of the wells and even penetrated and plugged the oil and gas sands.

Obstruction of the wells took place through the corroded tubing, sucker rods and other pumping equipment, parted, collapsed or telescoped casing that had been weakened by corrosion and by the incrustations of mineral salts and corroded products. Conditions also were developed which made it impossible to plug abandoned wells. Pumping operations were interfered with by the sanding up of the working barrels with the muddy and granular products of corrosion. The equipment was fouled and abraded by the

mineral scale deposited with the water and by the scaly products of corrosion which adhered to it.

This all resulted in the loss of production through inefficient pumping, the loss of operating time, premature declines in the rate of production, incomplete drainage of the sands and the abandonment of wells and fields.

For years, many oil producers considered that the loss through corrosion was unavoidable and necessary. They made little or no effort to study the problems involved or prevent this waste, although cheap and effective means had been developed and were in successful operation in other fields, which greatly reduced or eliminated these corrosion troubles. The producers could not overlook the mechanical troubles which resulted, and they had to put up with them. But such troubles were comparatively small compared to the damage to the oil and gas sands which could not be seen and to which no consideration was given.

The principal cause of the corrosion of oil and gas well equipment came from the water contained in the sands above the pay which were penetrated in drilling the wells. Iron or steel casing was used to prevent this water from moving from one stratum to another and percolating into the oil or gas sand. Unless shut off, the water encountered above the oil and gas sand surrounded the outside of the casing and entered between the casings when more than one string was used. In some fields, water was found in the lower part of the oil or gas sand or directly underneath which entered the working cavity of the wells.

In order for corrosion to take place, it is necessary for the water to contact the metal equipment and some types of these waters in the strata above the pay sands are vigorous agents of corrosion. Certain gases in oil and gas wells, such as carbonic acid and hydrogen sulphide which occur as impurities in natural gas and are dissolved in some oils and waters, are also very corrosive.

The circulation of water tends to increase the rate of corrosion. When gases and other corrosive or stimulating agents from extraneous sources are excluded, the corrosive qualities of the waters which come in contact with the casing tend to spend themselves if these corrosive agents are not replenished through circulation.

The principal method used for the prevention of corrosion is to stop the corrosive waters and gas from coming into contact with the well equipment and to prevent their circulation. Important progress has been made in protecting the casing from contact with these waters and gas.

Mud laden fluids are forced into the water and gas bearing sands and between the casing and the rock or earth walls of the wells. This fluid enters the pores of the water or gas sand and renders it impermeable, thereby preventing the infiltration of the water and gas into and around the casing. The effect is accentuated by the pressure of the column of mud.

In fields where the corrosion of casing had been very serious, the casing protected by the mud laden fluid has been in continuous service for over twelve years, whereas the casing in nearby wells not so protected has been corroded within four years. In other fields where the casing would not last for over two years, the mud laden protected casing has been in use for over twelve years with no evidence of corrosion.

Companies have found that the landing of their casing in heavy mud fluid prevents rusting and the ordinary disintegration of the pipe in certain fields where the casing usually became useless at the end of five years. This mudding can be done at nominal expense, and it is one of the most effective as well as one of the least expensive methods of protecting the casing of the wells against corrosion from the outside.

Its use has been improved by adding alkali reagents to

the mud mixture. Up to 1%, the addition of alkalies to the clay used has been found to be beneficial, but beyond that amount the mud may thicken and the clay settle out of the fluid. Alkali clay not only affords a chemical protection against corrosion but it reacts with certain dissolved constituents of oil field waters and forms precipitates in the pores of the water sands which aid in the exclusion of the water.

Cement shut offs are also used to protect the casings against outside corrosion. They have been in operation since 1917. This cement is forced into the water and gas sands and into the spaces outside of the casing. When it hardens, it prevents the outflow of water and gas.

Bottom water which rises inside the oil string is now shut off by cement, lead and other plugs in many instances. This not only prevents the corrosion of the inside of the pipe but it stops to some extent the entrance of the bottom waters into the oil and gas sands. In some pay sands, water is found at the bottom or just below and is often penetrated in drilling the wells. In many cases, this water can be shut off by the use of cement or other plugs.

Even after corrosion has begun in casing which has not been properly protected it is now customary to run thick mud or cement between the strings or outside the casing, where it settles by gravity and seals up the leaks. Further corrosion is thus prevented.

No one single remedy has been found for corrosion troubles in oil and gas fields, but the excessive losses through it have been greatly decreased by systematic effort. Most of the desirable qualities in metals used for oil field equipment are now known, and the necessity of excluding corrosive waters and gases or preventing their unnecessary circulation is fully realized. Precautionary measures are taken when the wells that encounter corrosive waters or gases are first drilled and equipped, and losses of crude oil and gas are thus prevented.

At this time, there are special corrosive problems for the oil operators in the Panhandle and West Texas fields on account of the hydrogen sulphide gas in the oil. It is reported to be costing the operators at least $1,000,000 a year. This does not represent losses of crude oil but consists of the replacement cost of the drilling equipment and the casing and tubing of the wells which have been eaten away. However, these problems are gradually being solved by the companies and such corrosion will be prevented to a substantial extent.

Losses of crude oil and natural gas occur during pipe line transportation through leaks in the pipe, but they have been considerably reduced by the improvements made in the construction of these lines. Leaks result from pits in the pipe. They may occur shortly after it is laid or at any future time, when rust has penetrated to the necessary depth. Some soils in which the pipe line is laid contain waters which have a corrosive effect on the pipe.

For years, the pipe line companies have been studying these problems, and they have developed means for the prevention of leaks and consequent losses to a substantial extent through improved methods of cleaning and protecting the pipe. Before it is now laid, all the mill scale and rust are removed by machines consisting of revolving cutters carrying thousands of sharp teeth hardened by a special process. They take off all mill scale, dirt and impurities and dig out the rust. The pipe is then cleaned by stiff wire brushes, which remove all the dust and dirt and polish it to a high degree. Protective coatings are then applied, which prevent some of the former leaks and losses and increase the life of the pipe lines.

Not only is the new pipe properly cleaned and scoured and protection coats applied but some of the older pipe lines are being raised, cleaned and scoured and treated with the required number of protective coatings. The pipe line is

raised above the surface of the ground, scientifically cleaned, scoured and polished, treated with the required number of protective coats and then relaid without interrupting its operation.

Formerly leaks in pipe lines were shown by the many pools of oil along their routes. But they are now a thing of the past. The companies employ line walkers who have their own sections to inspect every day. All leaks are reported promptly and repaired at once. A check is made of the quantity of oil passing through each pumping station. When any decrease appears, its cause is quickly found and corrected. If any considerable amount of oil has come through a leak, portable pumping outfits return it into the pipe line.

Losses have been further reduced by the better couplings used, the modern methods of laying the pipe, the improved machinery used at the stations and by the present equipment, which will stand greater strains than that formerly employed. The storage tanks at the pumping stations are now used to hold a small reserve of crude only, and very little oil is passed through them. Evaporation losses have thus been minimized.

There has been a hearty cooperation between the Federal Government and the oil companies in the study of corrosion problems and losses and the development of means for their prevention. Our Government is entitled to much of the credit for the reduction of these losses.

During the past few years, no fields are reported to have been ruined by water intrusion resulting from corrosion or the infiltration of bottom waters. Certain ones have been affected by such waters, but between the activities of the Federal Government and the oil companies, they have been plugged off and serious damage prevented.

Waste of Oil and Gas.

There has been some waste of crude oil in certain fields during the past years. It was caused principally by the sudden blowing in of wells or their unexpected drilling in where operators had failed to provide tankage for the proper storage of the crude before pipe line connections could be made. This was accentuated by the inadequate devices existing at the time for preventing or holding back the flow of oil which came in under heavy pressures. Waste also occurred through flowing the oil into earthen pits from which seepage and evaporation losses took place.

Some wildcat wells could not be brought under control as soon as they came in, and oil was sprayed over the contiguous area. But all this oil was not lost. It was saved as far as possible by the erection of dams, which prevented its spreading over the ground.

Years ago, some of this uncontrolled crude oil ran into the nearby streams. Dams were then built and oil soppers would hook up a pump with second-hand pipe and skim the oil from the surface of the water. Some of these plants recovered from 500 to 600 barrels of crude a day. In the aggregate, considerable of the spent oil was saved, but all of it could not be recovered.

There was a large waste of oil in the Spindletop field in 1902 and 1903. Some of the old operators state that nearly as much oil flowed into the bayous as was sold for commercial purposes. It is a tradition that more oil was run down the creeks in the famous Glenn field in Oklahoma than had been produced in the state of Illinois. That would lead one to believe that this waste was enormous, unless he took into

consideration that the total production of Illinois was only 187,660 barrels up to 1906, when the Glenn field was opened up. At Cushing in 1913-1915, considerable oil was wasted. Some wells in California and other places since then have broken loose with the consequent loss of crude.

Practically all these losses came from the lack of proper storage and pipe line facilities and the inability of producers to control the flow of wells when they were first brought in under heavy pressures. Oil was then sold at comparatively low prices, and the waste of a part of it did not seem of much importance to the oil operators in view of the gusher productions of these fields. Practically, all this waste took place prior to 1916.

Very little crude oil has been wasted in the fields during the past ten years. There are still instances of waste when wells run wild, but the control problems of the olden days have been solved.

Other than the waste in the Cushing field in 1913-1915, the important loss of crude oil at that time—it may have continued to 1919—was limited almost entirely to the waste of the residue which was settled or steamed out of emulsified oils. Oil is emulsified in various ways: by drilling some wells too deep and tapping the water zone beneath the oil sand which often resulted in an emulsified mixture of oil and water; by water under high pressure which was not plugged off but was forced into the oil; by overpumping wells thereby drawing water into the oil; and by gas which sometimes cut the oil and formed emulsions when water was present.

Emulsified oil was produced in a number of fields. It was not a commercial product until the water and basic sediment were settled out, either in large wooden or earthen tanks or through a steam treatment. The residue was not salable.

Operators who were particular about the condition of their leases collected this residue and burned it periodically. Others ran it over the ground, and it sometimes flowed down the gullies into the streams.

Fortunately, the amount of this residue was comparatively small compared to the crude produced, but much of it contained a large percentage of petroleum products. Its burning or waste did comprise a distinct economic loss, which was afterwards stopped. At the then comparatively low prices of crude oil and in view of its large production, the residue could not be used commercially. When a demand was created, this waste was prevented.

Drilling methods have since been improved to a point where producers are able to prepare for any emergency. Samples of the earth formation from the drilling wells are now taken out when probable producing horizons are neared, and drillers and geologists are able to tell if they contain gas or oil in commercial quantities. When approaching possible gusher sands under heavy gas pressures, some wells are deepened with a very small bit so that there is not the danger of a blowout which might occur if a larger one were used.

Further precautions are taken by placing high pressure control heads on the top of the casing. Master gates are put on, which can be closed and the wells shut in until provision is made for handling the oil or gas. A series of high pressure fittings known as a Christmas tree are attached to the casing in fields where oil is produced under high pressures, and blowouts are thus prevented.

In proven territory, further precautions are made through the installation of oil and gas separators before the wells are drilled into the productive sands. Stock tanks are erected and arrangements made for pipe line connections.

This former waste is now a thing of the past. Practically all wells are completed without losing an appreciable amount of oil. The industry has been saving every possible barrel of oil for some years and waste of oil has been reduced to the ultimate minimum.

In the Seminole fields, which have produced over 140,000,000 barrels of crude, less than 25,000 barrels flowed on the ground notwithstanding the fact that the muddy and almost impassible condition of the roads often delayed the installation of tanks and pipe line connections. Most of these 25,000 barrels were afterwards recovered from the pits which were dug to catch the oil.

Less than 0.02 of 1% of the Seminole production never touched the derrick floor or the ground. Almost all of the one barrel out of each 5,600 barrels produced that did flow upon the earth was afterwards saved. Gushers making upwards of 5,000 barrels a day were connected with the tanks or pipe lines with the loss of less than five barrels of oil throughout the entire operation, and there were no wastes after the connection had been made.

The waste of oil has been more spectacular than serious. We are always prone to allow our judgment to be unduly influenced by extraordinary scenic displays or by any unusual event. Hundreds of thousands of oil wells have been brought in without wasting any crude oil, and nearly all fields have been operated without losing this natural resource.

A few wells have unexpectedly blown in and decorated the landscape. It is still easy to conclude from the photographs of a few uncontrolled gushers that a large amount of crude oil was wasted, if we forget the many producing wells which did not show any losses and the many fields in which all the oil is conserved.

But be the past waste of oil as it may, the age of the oil sopper is past. Periodic inspections of the oil fields made

by the writer during the past ten years have shown no material waste of crude.

In former years, there was substantial waste of crude oil at refineries through leaks, overflows and the washings from the stills. Practically all such crude and the petroleum content of the still washings are now recovered in the up-to-date refineries through their collecting and separating systems. Thousands of barrels of crude oil a day are now conserved and pumped back into the refinery systems from these separators.

Important wastes of crude oil also occurred at tank farms through the burning of bottom settlings. They comprise the heavy grease-like products precipitated out of the crude oil in storage and found at the bottoms of storage tanks which have been filled with crude oil for some time. They were formerly considered an unusable and a necessary waste product resulting from the storage of crude and a total loss. They were shoveled out of the tanks and burned.

Some years ago, it was developed that this formerly wasted material could be utilized to obtain gasoline, kerosene and other refined products. While their separation from the water and basic sediment in the tank bottoms involves somewhat difficult problems, it is now being effected. These bottoms show as high as 75 or 80% or more of petroleum products. One large company has reported the following recovery from 468,000 barrels of tank bottoms:

TABLE 55.

RECOVERY OF REFINED PRODUCTS FROM TANK BOTTOMS.

Products	Barrels Recovered	Percentage of Amount Treated
Gasoline	52,000	11.1%
Kerosene	56,000	12.0
Gas oil	70,400	15.0
Lubricating oil	35,200	7.5
Wax	126,800	27.1
Coke	10,500	2.3
Losses	117,100	25.0
Total bottoms treated	468,000	100.0

There are millions of barrels of these tank bottoms in the storage tanks in the United States. They have now become of considerable value and a substantial stored reserve of crude oil instead of being the total loss that they were formerly considered.

State laws against the pollution of waters have done much to prevent the waste of crude oil both in the fields and at the refineries. These waters were and are rigidly inspected for signs of waste oil. Furthermore, oil companies were constantly bothered with law suits brought by farmers for the death of live stock which occurred at or near the streams which ran from or through the oil fields.

The multiplicity of these damage suits created an added incentive for the producers to prevent any waste of petroleum. They were expensive to fight and very annoying. Practically every time that a cow or horse was found dead near these streams, the oil companies were blamed, and it was alleged that that death occurred through the drinking of waters polluted by waste oil. It made little or no difference whether or not death was the result of broken necks, diseases or natural causes. The best protection and defense

that could be devised by the companies was the prevention of all waste or flow of crude oil into the streams.

There have been large wastes of natural gas in the United States, and they probably comprise the greatest economic single loss in the petroleum industry.

Perhaps the largest waste was that of the casinghead gas which comes with the oil from producing oil wells. Operators were almost solely interested in getting the most valuable raw material, crude oil, especially in new fields. The attendant flow of gas was considered to be of value in bringing out large quantities of oil or it was deemed to be a necessary evil in oil production. Where gasoline was extracted by casinghead gas at the compression plants, an important loss came through the waste of the tail or residue gases which were spent in the air.

The next important loss of natural gas consisted of the bradenhead gas, which comprises the gas contained in the sand which are above the oil producing horizon and through which it was necessary to drill in order to reach the oil sand.

Other waste of natural gas was that of the dry gas which was produced in fields which yield gas only and from some wells in the gas area of certain oil fields.

Casinghead Gas. This gas was utilized to bring the oil to the surface of the ground. Formerly both the oil and the gas were flowed into receiving tanks, from which the gas was vented into the air. Operators believed that this waste was necessary in order to force the oil to flow in large quantities. The gas was allowed to blow the oil into the tanks and its full volume was spent without restriction. It was often so rich with gasoline vapors that it sank to the ground.

Bradenhead Gas. Where the gas from the sands above the oil producing horizon was under any substantial pressure, drillers for oil often permitted it to exhaust itself in the atmosphere until the pressures were reduced to a point where drilling could be resumed. Much of this gas was formerly wasted. It could have been saved by sealing off the gas sands which had been practiced for many years.

Natural or Dry Gas. This gas freely escaped into the air from some wells which were allowed to blow openly. The greatest waste came from the "wild" wells which were allowed to flow under their own pressures until they were reduced to a point where the wells could be easily and cheaply closed. Prior to 1910, the development of most gas fields usually resulted in one or more wild wells which were not easy to close under the methods then in vogue. But the loss became so large and important that great ingenuity was developed in closing the wells against very heavy pressures, and large sums of money were spent in devising means for doing so. It was reported in 1911 that there was only one wild well which was not closed on account of the expense of the operation.

The waste of natural gas had been practically eliminated in the old fields prior to 1909, and the large waste of 1909-1913 came from certain fields in the Mid-Continent area.

In the 1913 survey of the Bureau of Mines, it was estimated that an average of about 300,000 cubic feet of casing-head gas per well had been wasted from about 20,000 productive oil wells in the Mid-Continent fields and that the total waste of this gas was about 6,000,000,000 cubic feet a year. The waste of all gas in Oklahoma was estimated at 150,000,000,000 cubic feet up to 1910 and at 100,000,000,000 cubic feet annually in 1910 and 1911. The 1912 loss had been materially reduced. It was placed at 25,000,000,000 cubic

feet for that year and approximately the same for 1913. An estimate of 425,000,000,000 cubic feet was made as the total waste of gas in the Mid-Continent field up to 1914, and it was figured that the loss for that year would not be over one-half that of 1913, or 12,500,000,000 cubic feet.

Natural gas has a heating value of 1,000 B. t. u.'s and upwards a cubic foot. Figured at 1,100 B. t. u.'s per cubic foot and converted into fuel oil, the estimated waste of gas in the Mid-Continent field was equal to 77,917,000 barrels of fuel oil to 1914.

There were 136,715,000,000 cubic feet of natural gas consumed in the Mid-Continent field in 1913, so that the estimated waste to 1914 represented a three years' supply. But based on the total consumption of 581,898,239,000 cubic feet in the United States for that year, this estimated waste would have supplied the nation for less than nine months.

Partly through the development and application of proper means for shutting in the gas which were brought in under very heavy pressures and the prevention of other gas losses and the utilization of casinghead and other gas, the production and consumption of natural gas in the Mid-Continent field in 1919 was practically twice that of 1913. In 1926, it was five times that of 1913, while the total production and consumption in the remainder of the United States had increased by less than 50% during that period. Evidently, the Mid-Continent field had made great strides not only in conserving gas but by increasing its output.

The waste of natural gas in the Mid-Continent field was accentuated by quick and faulty methods of drilling and of the setting of casing and the improper spacing of wells. Much of the gas was wasted by flambeau lights. There were between 2,000 and 3,000 of these torches in this field in 1913, which burned day and night near drilling wells, dwellings and power houses. Light was necessary for night drill-

ing, but these torches were not extinguished during the day time. Most of this gas so burned was casinghead, and oil operators claimed that the yield of oil would be diminished if it was turned off. Eventually, laws were passed to prevent this burning of natural gas in flambeau torches.

Gas was further lost by leaky gas pipes, which wasted hundreds of thousands of cubic feet a day and which were not properly repaired as the gas was so cheap.

After natural gas was collected for consumption, further waste occurred through the flat rate charge in the towns supplied. In some cities, no meters were installed, and the gas was sold at a flat rate for each stove, heater and light used. Most of the heating and lighting devices were allowed to burn all day, and temperatures were regulated by opening and closing the windows.

The past waste was also increased by the low price of the gas, so that there was little or no incentive for its conservation. Manufacturers were encouraged to locate in certain towns through the promise of free gas. This caused an important waste and the eventual depletion of the gas in the surrounding area. In many localities, it brought from 2 to 3 cents per thousand cubic feet. In towns, the gas was sold for less than 16 cents for industrial purposes and at 25 cents and under for domestic uses.

Past losses or waste of natural gas have been caused by various factors:

The ignorance of the oil and gas operators of its real value both for the production of oil and its gasoline content.

The many thousands of operators on which the loss fell. Where a partial concentration of this loss was borne by a few operators, it led to careful study and the development of means for its prevention.

The low price then prevailing. A by-product natural resource may be wasted when it has a low value, but when

the dollars and cents loss become important and mount to fair figures, means are devised for its conservation.

While there was a considerable waste of natural gas in the Mid-Continent field up to twelve or so years ago, the amount was grossly exaggerated in the literature and comments of those days. They were chiefly limited to the magnitude of the waste and were timed for sensational effect, according to some of the reports of the Federal Government. Contrasted to these reports of waste were the efforts of the oil and gas companies to prevent all waste and their investment of large capital, to check not only the waste of gas but for the recovery of its gasoline content through the erection of natural gasoline plants.

A résumé of the natural gasoline plants in the Mid-Continent field and the amount of natural gas treated indicates the extent to which the oil industry has gone in order to prevent the waste of one of the constituents of natural gas. Table 56 shows an increase of 25,920% in the amount of natural gas treated in the gasoline plants in 1926 over that of 1913. This is one of the outstanding developments of any industry.

TABLE 56.

NATURAL GASOLINE PLANTS IN THE MID-CONTINENT FIELD AND THE AMOUNT OF NATURAL GAS TREATED.

Year	Number of Plants	Cubic Feet of Natural Gas Treated
1911	8	145,000,000
1912	13	701,000,000
1913	40	2,153,000,000
1914	58	5,739,000,000
1915	63	8,792,000,000
1916	131	28,232,000,000
1917	271	108,946,000,000
1918	318	116,301,000,000
1919	389	146,324,000,000
1920	398	150,371,000,000
1921	382	168,169,000,000
1922	358	202,568,000,000
1923	434	353,058,000,000
1924	455	476,152,000,000
1925	473	492,161,000,000
1926	512	579,641,000,000

Utilization of Natural Gas.

No comment is necessary on the superior qualities of natural gas for domestic uses, especially after the gasoline content has been taken out in the natural gasoline plants. The extraction or conservation of the contained gasoline does not materially affect the heating value of the gas. It removes the cause of former vapors and greasy deposits. Natural gas is a clean fuel, easily controlled and instantly available.

For industrial purposes, it is the ideal fuel, especially for those manufacturers who require a steady, constant and easily controlled heat for their operations.

Natural gas is used where available in the ceramic industry for the production of pottery, cement, lime plaster, enamel ware, glass, terra cotta, white wear and other products where the efficient application of heat is the most important part of the factory operation. It is especially desirous in metallurgy and is used in open hearth steel furnaces, for forging, annealing, hardening and tempering. There is a large consumption in the Pittsburgh district and other centers where it is available.

The gas is collected and transported to consuming districts by a system of over 75,000 miles of natural gas pipe lines, and its users now number more than 3,500,000 individuals and companies.

Its advantages can be summarized as follows:

Adaptability to all furnace conditions;

Lowest melting cost per pound of product;

Less harmful effect on the finished products and their resultant high quality;

Lowest oxidation;

Less shrinkage loss due to its easy firing and regulation;

No consumption or waste while furnaces are being held on account of delays or emptied;

It gives more heat per unit in the crucible type of furnace than any other fuel;

Quickness in obtaining heat, which saves time and increases the output of the furnaces;

Requires no storage or labor cost of handling;

No ash or waste from its use;

Requires no investment in fuel stock;

Meets all insurance requirements;

Extremely small initial investment for equipment.

The intangible results of its use are as follows:

Clean shops and no fumes, which provide cleaner operating conditions for employees and decrease the labor turnover;

Service at all times and increased production through 24 hours of service per day, if required;

Cleaner cities and towns.

Natural gas is also the source of helium, the non-inflammable gas which is being used in our dirigibles.

The increase in the consumption and production of natural gas is shown in the next table with the equivalent in barrels of crude oil, based on 1,050 B. t. u.'s per cubic foot of gas.

TABLE 57.

PRODUCTION AND CONSUMPTION OF NATURAL GAS IN THE UNITED STATES IN CUBIC FEET AND THE EQUIVALENT IN BARRELS OF FUEL OIL.

Year	Cubic Feet of Natural Gas	Equivalent in Barrels of Fuel Oil: Total	Equivalent in Barrels of Fuel Oil: Average Daily
1910	509,155,000,000	89,102,125	244,100
1911	512,993,000,000	89,773,775	246,000
1912	562,203,000,000	98,385,525	268,800
1913	581,898,000,000	101,832,150	278,900
1914	591,867,000,000	103,576,725	283,800
1915	628,579,000,000	110,001,325	301,400
1916	753,170,000,000	131,804,750	360,100
1917	795,110,000,000	139,144,250	381,200
1918	721,001,000,000	126,175,175	345,700
1919	745,916,000,000	130,535,300	357,600
1920	798,210,000,000	139,686,750	381,700
1921	662,052,000,000	115,859,100	317,400
1922	762,546,000,000	133,445,550	365,600
1923	1,006,967,000,000	176,219,225	482,800
1924	1,141,482,000,000	199,759,350	545,800
1925	1,188,439,000,000	207,976,825	569,800
1926	1,312,853,000,000	229,749,275	629,400

A Government report of 1923 contained an estimate that from one-third to one-half of the natural gas produced in the United States in 1921 was wasted. The progress since then in the utilization of casinghead and natural gas for the production of gasoline and the increase in the consumption of gas in the United States are shown in the next table.

TABLE 58.

Year	Gas Treated at Natural Gasoline Plants in Cubic Feet	Total Gas Consumed in the United States in Cubic Feet
1926	1,206,300,000,000	1,312,853,000,000
1921	465,097,000,000	662,052,000,000
Increase	761,203,000,000	650,801,000,000
Percentage of increase	163.7%	98.3%

The natural gas consumed in the United States in 1926 was equivalent in heating power to over 53,000,000 tons of coal, which would have required about 1,000,000 cars in order to transport it from the mines to consuming centers. This lightened the burden of the railroads to that extent and amounted to a substantial conservation of coal, if the same had been used to supply the power and energy produced from the natural gas.

Natural gas is of the utmost importance in the production of crude oil. It becomes dissolved in petroleum when under pressure and increases its fluidity so that it flows more readily. It further comprises the stored energy which acts as the motive power which forces the oil through the sands into the wells and then causes it to flow to the surface. The important progress in producing methods in the past few years has been towards the utilization and conservation of this fluidizing and motive power of natural gas as the prime mover and lifter of crude oil in the following ways:

Through stop-cocking, by which a well is shut in and opened up at such intervals as will permit sufficient crude oil and pressure to accumulate at the bottom of the wells so that an intermittent flow of oil can be made.

By the insertion of tubing into the casing of the well. This prevents the free flow of the oil and gas and conserves the stored energy of the contained natural gas for a long period. It steadies crude production and results in its greater ultimate recovery from the sands.

The use of beans by which the flow of oil is restricted

by steel nipples inserted in the flow lines. The size of the openings can be increased or decreased at pleasure, and these flow beans are of great value in conserving gas and gas pressures during the initial flow of wells under heavy pressures.

Gas lifts by which compressed gas is forced into a well. It not only increases the fluidity of the oil and, therefore, its mobility but utilizes the expansive power of the compressed gas for the flowing of the oil to the surface. This compressed gas may be injected down the tubing and thereby force the crude oil to rise in the casing, or it may be put down the casing and make the petroleum flow upwards through the tubing. The natural gas is afterwards recovered, stripped of its gasoline content and forced over and over again into the wells.

Through any of these methods of production, the amount of gas which it takes to lift a barrel of crude oil is substantially decreased, the rate of decline of production greatly diminished and the encroachment of water into the oil sands retarded. Furthermore, it is the opinion of most engineers that a greater ultimate recovery of crude oil from the sands will be made, which provides additional reserves of this natural resource.

A further use of natural gas is being made by the injection of compressed gas into the oil sands through a central or key well, by which the gas pressure is more or less maintained and the flow of oil towards the wells accelerated and production increased.

Natural gas is also forced into oil sands in order to build up the pressures and increase the mobility of the oil so that it will move more freely both towards the bottoms of the wells and to the surface of the ground.

It is probable that this use of natural gas which is now undergoing development will become an important factor for the recovery of a larger percentage of the oil content of the sands and in the more efficient and economic production of petroleum.

Carbon Black.

THE NATURAL GAS INDUSTRY is peculiar inasmuch as this natural resource can be and is utilized to a substantial extent in the natural gas fields which are far removed from industrial centers and to which no pipe lines have been constructed. This use consists in its consumption for the manufacture of carbon black, which results from the incomplete combustion of gas in plants erected for that purpose. It is deposited by the actual contact of the burning gas with a metallic surface.

The first factory for the production of carbon black on a commercial scale was erected at New Cumberland, W. Va., in 1872. No regulating device was then known, and the surplus gas was vented into the air and wasted. The first lot of 500 pounds of carbon black was sold at $2.50 a pound, the next 1,000 pounds at $1.50 each, and the plant paid for itself in about three months.

Carbon black consists of extraordinary fine particles. It is the most finely divided pigment known and has been aptly termed "congealed smoke." The minuteness of its particles gives it a very large covering power when used in the manufacture of printers' ink and as a reinforcing or strengthening agent in rubber compounds. It has a very intensive color and mixes readily with oil, rubber and other plastics.

The growth of the industry was coincident with the development of rotary printing presses, which require a thin rapidly flowing ink of great covering power. Within the past ten years, a further impetus was given to the industry

by the discovery of its value in the manufacture of rubber compounds. This is considered one of the most notable achievements of the rubber chemists since Goodyear's discovery of the art of vulcanization.

The carbon black industry is peripatetic. Originally, Pennsylvania was the principal place for the production of carbon black. But as natural gas became more valuable through its consumption for domestic and industrial purposes, the carbon black plants were forced to move to West Virginia. Here the same process went on and the gas became too valuable for the production of carbon black. West Virginia's output in 1920 amounted to 26,659,469 pounds and was 51.9% of the entire United States production, but it had decreased to 3,804,586 pounds in 1926, which was only 2.1% of this country's output.

Next, the industry moved to the Monroe gas field in Louisiana, which is now producing approximately 70.0% of the total. But eventually, the factories will have to move again as a pipe line has been recently laid from this field to Baton Rouge and other Mississippi and Louisiana cities, and in time, all the available gas in the Monroe field will be used for domestic and industrial purposes other than the manufacture of carbon black.

Plants have been erected in Texas, and the next great fields for the production of carbon black will probably be in Panhandle and southern Texas. Some plants have been erected in other places which use the residual gas from natural gasoline factories which is not salable to other users.

Practically all the gas used at carbon black factories is being processed at natural gasoline plants and the gasoline first extracted. Only the residue gas is consumed in the carbon black factories. Some of the natural gas is so lean that the gasoline could not be recovered commercially unless the residue gas were used in making carbon black.

Carbon black is universally used in the manufacture of

printing inks. The early printer could collect enough soot for his ink by holding a saucer over the flame of a tallow candle. But the vast expansion of the printing and publishing business and the consequent demand for printers' ink has brought about new requirements as regards quantity, quality and cost. Multiple presses require an ink that will flow freely and cover every line of type and make an instantaneous jet black impression.

The ideal and indispensible ingredient of news inks is carbon black, and about one pound of it is mixed with eight or nine pounds of oil. A single pound of carbon black will print 20,000 pages of the average newspaper, the equivalent of nearly an acre of surface. In 1922, the Bureau of Mines stated that "Carbon black is peculiarly suited to the needs of the present methods of printing, the fast running presses and half-tone illustrations. * * * Ink manufacturers and users believe that it is absolutely essential to their business."

Carbon black is also used in carbon paper, phonograph records, paints, varnishes, enamels, stove polish, cement colors, crayons, black and gray papers, bookbinder's board, linoleum and artificial leather.

It is principally now used in the manufacture of rubber tires both in the United States and foreign countries. At least 100,000,000 pounds, or over 55.6% of the production, is so consumed yearly.

Carbon black increases the tensile strength and resiliency of the tires, toughens the rubber, increases the resistance to abrasion, minimizes punctures and blowouts and gives much greater mileage. A rubber sulphur mixture has a tensile strength of about 1,150 pounds. By adding an equal amount of zinc oxide, which was formerly used, this strength may be increased to 3,400 pounds. But by substituting 35% of carbon black for the zinc oxide, the tensile strength is reported to be increased to over 4,000 pounds,

The resultant compound is said to absorb shocks of almost double the rubber-zinc oxide mixture.

Rubber compounds as now made with carbon black will outwear leather by about 2½ times when both are dry, and more than 10 times if wet. This compound resists the action of a powerful sand blast about three times as long as iron. It is extremely useful in making balloon tires, which contain a less proportionate amount of fabric than cord ones, and the efficiency of balloon tires is dependent upon the use of carbon black.

The savings thus effected by carbon black make it a very important basic industry. By extending the life of tires to over twice that of the former ones, its use in conserving another important natural but not national resource, rubber, can be estimated from the $800,000,000 or so spent in the United States a year for automobile tires without taking into consideration the conservation of zinc oxide.

Carbon black is an ingredient of rubber products used for hose, surgical and mechanical rubber, floor composition, rubber heels and all other rubber products in which resistance to wear is the vital requisite. Recent developments are shackle bolts for motor cars and trucks, linings for ball mills, where it is superior to steel, and even rubber pavements, where it is desirable to deaden the noise of traffic.

Carbon black is an economic necessity at this time. The use of natural gas for its production is an important utilization of the natural gas and residue gas from natural gas plants which cannot now be used for domestic or other industrial purposes.

The manufacturers of carbon black conserve the crude oil, which would be required to be refined in order to produce the amount of natural gasoline now recovered from lean natural gas that would not be processed in natural gasoline plants were it not for the utilization of the residue gas for the making of carbon black.

Statistics of the carbon black industry are set forth in the next table, and they show some increase in the efficiency of the plants.

TABLE 59.

PRODUCTION OF CARBON BLACK, NATURAL GAS CONSUMED, ETC.

Year	Carbon Black in Pounds	Natural Gas Consumed in 1,000 Cubic Feet	% of Natural Gas So Consumed to Total Consumption in United States	Average Yield of Carbon Black to 1,000 Cubic Feet of Gas Used, in Pounds
1920	51,321,892	40,599,000	5.1%	1.26
1921	59,766,315	50,565,000	7.6	1.18
1922	67,795,129	53,629,000	7.0	1.26
1923	138,262,648	109,096,000	10.8	1.27
1924	186,872,034	156,514,000	13.7	1.19
1925	177,417,378	140,366,000	11.9	1.26
1926	180,576,176	130,321,000	9.9	1.39

Conservation of Life and Limb.

THE CONSERVATION of our natural resources is of great and growing importance, but it is second to the preservation of the lives and limbs of employees. The prevention of avoidable accidents conserves the life, health and physical capacity of workers and is closely allied with fire prevention and the resultant conservation of crude oil and refined products, as in many cases, fires are the direct cause of accidents.

There has been no single item of waste in modern industry in which the cost has been as high as that of accidents, many of which could have been prevented if proper precautions had been taken. Over sixteen years ago, the progressive companies began to realize the importance of the conservation of the life, health and physical capacity of their employees not only from the standpoint of humanity but also from that of the conservation of material, equipment and buildings. Furthermore, the costs of accidents had been a large expense, part of which could be reduced.

The National Safety Council was started. Annual meetings are held for the discussion, dissemination and propagation of means for promoting the safety of employees. Some of the progressive oil companies had been studying this problem for years. The important beginning of cooperation among them began in 1922, when eight executives met and exchanged information about accident prevention. Over 100 oil companies now belong to the Petroleum section of the Council.

Interest in safety measures has been increasing throughout all industries in the United States and is illustrated by

the growing attendance at the annual Council meetings. Over 2,900 representatives were present in 1927, the sixteenth annual meeting, or 800 more than had attended the previous one. Of this number, 100 or so represented the oil industry.

Accidents are very costly. Many of them can be prevented and that means also the saving of materials and money, a lowering of cost and the speeding up of production. Progressive companies have realized for some time that the management is entirely responsible for mechanical hazards and that safeguards must be installed before safety teaching can become effective. This work must start at the top of the Companies and never from the bottom if it is to be successful. Considerable money must be spent in order to make working conditions safer. The officers must approve these expenditures, and they should recognize that they are the most profitable investment of their stockholders' money that can be made.

While this is not realized by all oil companies, the larger and far sighted organizations have outlawed accidents as bad business, and their clear-thinking leaders know that they result in a waste of material and diminution of profits. These leaders cannot justify their positions as custodians of life and property until they have taken the proper precautions against accidents which result from defective and unprotected machinery and equipment and from mechanical failures.

A comparison of the cost of accidents for four companies is somewhat enlightening and is shown in the next table.

TABLE 60.

RESULTS OF INDUSTRIAL ACCIDENTS OF FOUR COMPANIES.

Number of Employees	Industrial Cost	Cost Per Pay Roll Employee
6,000	$64,000	$10.66
9,000	134,000	14.88
1,800	68,000	37.77
9,000	500,000	55.55

The first two companies had been engaged in accident prevention work for several years, while the others have become active only recently. Claims cost of the first two per employee averaged only 25.1% of that of the others.

But such costs are the least important part of the financial losses from accidents. It is reported that for every dollar spent for compensation and medical care not less than $4.00 are expended for incidental costs and losses. Wrecked apparatus, machinery, equipment and buildings, the waste of raw and refined material, the necessity for the training of new men, the added supervision of foremen, the upset of morale and the resultant labor turnover are items that can be approximated in dollars which are taken from the profits of operations. They comprise an important financial loss from accidents.

It has required a great deal of experience to arrive at the most effective working formula for the prevention of accidents. After all mechanical safeguards have been installed, there is much work to be done with the employees in order to make them realize the necessity of caution.

Safety work starts with the study of the accidents. The result of past experience passes through revision and consideration by the safety engineers and winds up with the education of the workers in safe practices. They comprise

the proper selection of men, their medical examination, proper instruction in the work at hand, the development of the full realization that the prevention of accidents is more important to employees personally than to the companies and the growth of a morale through which every worker is forced to recognize the personal element as well as the interest of his employees. The practice of making employees practical partners through the purchase of stock in the companies has been of considerable help in the carrying out of safety programs. The most difficult thing to teach the workers is that every scratch and cut should receive prompt medical attention by the doctors provided by the companies. But after one or more men have contracted blood poisoning through neglected scratches or cuts, other employees begin to realize that prompt attention to these matters is advisable.

Next to the safety engineer or director, the foreman is the key man. He can make or ruin a safety program as far as his authority goes. These minor bosses are made to realize that the leaders of their companies are vitally interested in safety and that they will be held accountable for the men under them.

One of the important steps in safety work is to get an accurate account of every accident that requires first aid or medical care, to fix the responsibility and to bring it home to the person whose neglect was the cause. Committees of workers are formed in some plants who hear the evidence of the accident and fix the blame. Safety committees are elected who are required to make periodical examinations of equipment. They are changed each month in some refineries. In this way, more men are familiarized with the work in hand, and the safety director is able to get in touch with all employees. Through proper education, more accidents can be prevented than by the elimination of the obvious dangers around the plant, and safety directors, if they

have the breadth of vision that the work requires, learn many things from the men themselves. The competent safety engineers not only see the obvious dangers that can be corrected but they are able to eliminate many unappreciated hazards.

After all mechanical safeguards have been installed, further accident prevention is brought about through the education of the workers to the full realization of the possible deaths, permanent and temporary injuries and lost hours and opportunities which result from accidents.

Figures are not available to show the decrease of deaths from accidents in the whole oil industry. This subject is worthy of an extended study similar to that recently made in California. The Bureau of Mines has issued a report that shows a substantial decrease in fatal accidents in the oil industry in California, which is summarized in the next table.

TABLE 61.

FATALITIES IN THE CALIFORNIA PETROLEUM INDUSTRY.

Year	No.	Decrease from 1923	Barrels of Oil Produced	Fatalities Per 100,000,000 Barrels	Decrease Under 1923
1923	59	....	263,728,895	22.3	....
1924	44	25.4%	230,063,117	19.1	13.9%
1925	31	47.5	230,147,342	13.5	39.5
1926	25	57.6	224,117,013	11.2	49.8

This decrease in deaths in California is more remarkable than the figures show when one takes into consideration the substantial increase in two hazardous branches of the oil industry, refining and the manufacture of natural gasoline. In 1926, there were 200,876,000 barrels refined,

compared with 150,205,980 in 1923, or an increase of 31.5%, and 9,270,000 barrels of natural gasoline were produced, compared with 5,033,000 in 1923, an increase of 84.2%.

If the 1923 rate of deaths had prevailed in 1924, 1925 and 1926, there would have been 53 men now living who would have lost their lives. The survival of these men comprises an eloquent indorsement of the result of safety work. There is a direct relationship between the prevention of deaths and the waste or destruction of property. This decrease of 57.6% in fatalities in California means a substantial conservation of property as well as life. Translated into dollars, it represents important savings for the stockholders.

More statistics about accidents should be gathered in order that those interested in the oil industry can find out what is being done for the employees of the companies. Data obtained from a number of large companies show a substantial reduction in the number of accidents and lost hours during the past few years. A truly remarkable record was made at one refinery and is shown in the next table.

This refinery employed an average of 3,585 men during the period. It has a large installation of cracking units, which is the most hazardous branch of the oil industry.

TABLE 62.

Lost Time Accidents at One Large Refinery.

Year	Total	Accident Per Employee	Decrease Under 1917	Days Lost Per Employee	Decrease Under 1918
1917	624	.187	....	not avail.	....
1918	517	.1508	19.3%	.695	....
1919	371	.0923	50.6	.511	26.5%
1920	362	.0958	48.8	.495	28.8
1921	205	.0665	64.4	.465	33.1
1922	121	.0395	79.9	.369	46.9
1923	134	.0364	80.5	.425	38.9
1924	87	.0210	88.8	.294	57.7
1925	65	.0175	90.6	.270	61.2
1926	72	.0188	89.9	.292	57.8
1927	64	.0172	90.8	.276	60.3

The 1927 figures is the annual rate, based on those for the first ten months.

Résumé.

The oil industry has not only been severely handicapped in building up large reserves of proven oil lands for our future needs by the laws which prevent cooperative efforts and agreements for the economical development of new oil fields—and therefore their resultant conservative drilling and operation—but it has been suffering temporarily from the remarkable advances made by it in engineering and geological practices for the discovery of oil fields and deeper sands, in producing, refining, cracking and storage methods and in the utilization of natural gas and petroleum products. The culmination of this progress during the past year or so has resulted in an overproduction of crude oil, which would probably not have occurred if operators had been allowed to enter into agreements to develop the new fields in a conservative manner.

Stocks of crude oil east of California were increased by 73,382,000 barrels in 1927, while those of crude oil and fuel oils in California were reduced by 6,276,000 barrels. The amount of refined products and natural gasoline on hand also decreased by 3,019,000 barrels, so that the net addition to all stocks of crude oil and refined products was 64,087,000 barrels for the year, or at the rate of 181,112 barrels a day.

The five Seminole fields produced approximately 133,-064,000 barrels of crude oil in 1927. Probably over one-half of that production can be attributed to the progress made in the development and installation of compressed gas and air lifts in these Seminole fields. This method of production brings to the surface of the ground within a year or so, a large amount of crude oil which would otherwise be pro-

duced over a period of years. It is also being used in several other producing fields. If it had not been applied to the Seminole fields, it appears that there would not have been any overproduction of crude oil in 1927 and that stocks would probably have been drawn on to some extent.

The trouble with the oil industry during the past few years is that it has become too efficient for its own welfare and that of its stockholders; and that neither of them has yet begun to reap the benefits of its progress along all lines.

Any important delay for only a short time in its progress in

The discovery of oil fields and deeper sands;

Improved production methods;

The increasing efficiency and number of cracking plants;

The increasing efficiency and number of natural gasoline plants;

The installation of refinery improvements;

The utilization of natural gas for fuel purposes; or

The reduction of evaporation and other losses

would have more than offset the increased production of crude oil in 1927 and the addition to crude stocks, an increase due to the use of the improved compressed air and gas lifts in the Seminole fields.

This storage of 64,087,000 barrels in one year, based on the 17.1% of gasoline recovery from crude oil by refineries in 1914, is:

Less than 3.1% of the conservation of crude oil effected through refinery improvements and reduction of evaporation losses since 1915, and only 20.0% of that of 1927;

Less than 2.6% of the conservation of crude oil effected through the cracking processes since 1915 and only 10.8% of that of 1927;

Less than 5.7% of the conservation of crude oil effected through the production of natural gasoline since 1915 and only 28.4% of that of 1927;

Less than 1.2% of the total conservation of crude oil effected through refinery improvements and the reduction of evaporation losses, the cracking processes and the production of natural gasoline since 1915 and only 5.7% of that of 1927;

Only 10,087,000 barrels more than the estimated amount of fuel oil conserved by refineries through the use of refinery and stripped natural gas and heat exchangers and economizers in 1926;

Only 3 6/10th times the estimated yearly reduction in refinery losses.

This storage of 64,087,000 barrels in one year is:

Less than 14.5% of the 440,808,000 barrels of cracked gasoline produced in the United States since 1915 and only 63.3% of that made in 1927;

Less than 33.0% of the 194,303,000 barrels of natural gasoline produced since 1915 and only 1 7/10th times that of 1927;

Less than 21.9% of the estimated reduction in evaporation, corrosion, refinery and other losses of crude oil since 1915, based on an average annual saving of 4.5%, and only 1 7/10th times that of 1927;

Less than 3.3% of the 1,980,355,550 barrels of fuel oil, the equivalent in heating value to the amount of natural gas used since 1915 and only 25.6% of that of 1927;

Less than the fuel oil equivalent of the increase in the consumption of natural gas since 1923; and

Less than one-half of the increase in the consumption and exports of gasoline in 1927 over 1926 and less than the increase in the consumption and exports of fuel oil in 1926 over 1923.

But all these improvements have come to stay, and the oil industry would not turn backwards if it could. It has made and is now making every effort to increase the efficiency of all its practices, processes and apparatus for the further reduction of evaporation and other losses, a greater utilization of natural gas and more economical discovery and oil production and refining methods.

Competent engineers have reported that the compressed gas and air lifts result in the recovery of a considerably larger percentage of the oil content of the sands. That is a distinct economic achievement. Any production method that brings about a greater ultimate recovery of the crude content of the oil sands adds so much to our general oil reserves. In times of overproduction, which result principally from the intensive drilling and uneconomic development of oil fields, compressed air and gas lifts are temporarily inconvenient as they add so much more to burdensome stocks when they are not needed. But for our future requirements of crude oil, they are the outstanding improvements in production methods. They will be used in all oil fields where the conditions permit their application.

There seems to be a difference of opinion as to what constitutes the waste or economic loss of crude oil. Some hold that its utilization in the form of fuel oil, the present cheapest refined product, constitutes a waste of petroleum, the natural resource, as a large percentage of this fuel oil can be converted or transformed into the higher priced product, gasoline. Certainly, the oil industry through its expenditure of hundreds of millions of dollars has shown how this transmutation can be made and how the percentage recovery of gasoline from crude oil has been thereby greatly increased.

In the ultimate analysis, the consumption of fuel oil does not seem to be a waste. It is one of the cleanest and most attractive fuels. Stokers and firemen who now handle it

instead of coal, may readily assert that fuel oil represents the best utilization of crude petroleum. They would not be far wrong from their own viewpoint and comfort.

But at the same time, fuel oil is not the most effective utilization of petroleum; and coal, another natural resource, can be used to a great extent in its place. There are very large known reserves of coal in this country, compared to those of crude oil, and coal is not important at this time in the production of the higher and more volatile hydrocarbons which constitute gasoline.

Yet if the theory that a natural resource is wasted because it is consumed in an inferior form is the proper one, then the consumption of gasoline is a waste of crude oil, as there are other superior or at least higher priced products. The better grade of lubricants are of a present higher value. Other refined products like vaseline and Nujol sell for many times the price of gasoline. But it is impossible to utilize the present production of crude oil in the form of lubricants, vaseline and Nujol, as it is to use all of it as gasoline at this time.

This same theory of waste can be applied to any natural product, and we would find that practically the total amount of all natural resources is wasted. There is some superior, or at least high priced product, manufactured from every raw material which is consumed in small quantities only.

But whether or not this utilization of petroleum in the form of fuel oil is a waste or economic loss, crude oil is the present essential raw material which can be most readily, easily and cheaply converted into gasoline, and it constitutes our present principal reserve for this product. Crude oil is now, and it shall be for some time, vitally necessary in order to meet the ever increasing demand for gasoline, and gasoline is a modern requirement of this industrial age.

The conservation of petroleum for gasoline and lubricating oils through the substitution of coal for fuel oil, and the

conversion of the latter into gasoline seems advisable to a large extent. Modern cracking processes can reduce crude oil into gasoline and coke without producing the intermediate products of fuel oil and lubricating stocks. But losses of material become larger and larger as this ultimate is realized, until they reach a point where the re-re-re-cracking of cycle stock is not commercially practical.

Fuel oil is one of the most attractive of all fuels. It is a present important product of petroleum and a necessity in our present industrial age. It cannot be wholly replaced by coal in the factories and furnaces. However, substantial amounts have already been supplanted by the burning of natural gas after the gasoline has been extracted. The oil industry itself has decreased its consumption of fuel oil at refineries. More and more fixed and natural gases are being used, and such consumption should continue to increase. Furthermore, the burning of fuel oil for the making of steam has been supplanted to some extent by the use of Diesel engines, which are able to develop the same power with the consumption of less than one-half the fuel oil required in oil burners.

Pulverized coal is an excellent and clean fuel, and its increased use may reduce the demand for fuel oil. The continuing further demand for gasoline should work towards the decrease in the consumption of fuel oil. Relatively, a large reduction has already taken place. The consumption and exports of fuel oil in 1917 averaged 433,900 barrels a day, and the burning of crude oil as fuel averaged 141,200 barrels a day, or a total average of 575,100 barrels daily. That was 3 17/100 times the consumption and exports of gasoline in that year, compared to 1 1/5th times in 1927. It shows a reduction of 62.1% in the relative ratio of consumption of these two products. A further decrease should continue as gasoline becomes more and more in demand.

Further relative decreases should be effected through

the installation of more Diesel engines, the use of pulverized coal, the building of more water power plants and probably through the erection of great electrical plants at or near coal mines.

Today, fuel oil is a fundamental need of our industries, which cannot be changed over night. But that should not discourage work for the further conversion of crude oil into gasoline instead of burning one of its products, fuel oil, for power purposes.

The record of the oil industry indicates that it has done more than could have been reasonably expected of it in the cracking of crude oil and its heavier products into gasoline. No backward step is shown and the oil companies have freely used their financial resources and the skill of their employees. While it is difficult to conceive of much greater progress, there seems to be no impossibilities for the oil men and further advances will be made.

Much is heard about the waste of natural gas. But very little is now lost, at least compared to the former waste.

What has been and may now be wasted in some of the smaller and less important fields is the energy of the gas which is the primary cause for the movement of petroleum from the oil sands into the wells and its recovery from them. Very substantial progress has been made in reducing the gas-oil ratio, or the amount of gas which is required to lift a barrel of crude oil, during the past few years. The improved production method of compressed gas lifts conserves not only the original motive power of the gas but they restore energy to the gas again and again so that the same gas is repeatedly used for the bringing of crude oil to the surface of the ground.

Cooperation between our Government and oil producers has worked for the conservation of crude oil in its natural reservoir, the ground, in some fields. The studies and investigations of the Bureau of Mines in cooperation with the oil

companies have done much to decrease losses from evaporation, corrosion and water troubles, to increase the recovery of all gasolines and to bring about better refining and production methods. As the paternal relative who is interested in our well being and prosperity and as the landlord of the Public Domain, it is important that further cooperation be had.

Further cooperation between the Federal and State Governments and producers of crude oil should result in great strides towards the conservation of the crude oil in the ground, the recovery of a larger percentage of the oil content of the sands and the creation, development and conservation of important reserves. The oil companies have struggled for years to increase the efficiency of their methods and equipment and to prevent losses. The time should not be far ahead when they will reap the benefit of their effective work of the past ten years through increased prosperity and earnings, commensurate with the capital, energy and ability invested.

The oil industry is second only to that of agriculture. Instead of being the most unpopular and the least understood of all industries, it should rank as the most popular through its efficient service to the public and should become the best understood of all. The latter depends somewhat upon the dissemination of information by the officers and directors of the major oil companies.

No defense or excuse is needed by the oil industry, and it does not require propaganda in its favor. Its long record of development and progress is one of which any industry may well be proud. It has not only resulted in the conservation of petroleum and natural gas but the progressive oil companies have found it to the benefit of their stockholders to prevent all waste and to utilize the raw material in the higher forms. Their earning power depends to a great extent upon such conservation and utilization.

But when indicted as wasters of our natural resources, the leaders of the oil industry should give out facts and figures from time to time as to its development and progress in conserving the natural resources upon which its very life and earning power are dependent.

Other improvements and factors in the oil industry have brought about some conservation of crude oil. However, they principally resulted in important savings by the oil companies of their own capital and earnings. The standardization of materials is an illustration. But as the primary object was not the conservation of petroleum, their discussion is not included herein.

The Oil Industry and Conservation.

Our oil industry with an investment of over $11,000,-000,000, is second to that of agriculture. A substantial part of this capital has been put into cracking and natural gasoline plants and improved refinery apparatus and storage facilities, which have done so much for the conservation of crude petroleum.

The oil industry itself began on August 28, 1859, when Colonel Drake drilled the first well in Pennsylvania and obtained an initial daily production of 40 barrels at a depth of 69½ feet. Since then, 750,000 wells have been drilled in the search for petroleum and it has been found in New York, Ohio, West Virginia, California, Kentucky, Tennessee, Colorado, Indiana, Illinois, Kansas, Texas, Missouri, Oklahoma, Wyoming, Louisiana, Montana, New Mexico, Utah and Alaska. Test wells are being drilled in other states.

Important progress has been made in discovering oil through the advances in geology, petroleum engineering, geophysics and paleontology. Structures are defined through geological surveys and core drilling. Torsion balances, siesmographs, geophones and geographs have replaced wildcatting in locating and determining oil fields in some districts. Cores of sands are taken as wells are being drilled and their fossil contents examined in order to determine their oil bearing character. Much crude oil is now recovered from sands below 4,000 feet and the initial daily production of some wells exceeds 50,000 barrels.

Not over 25% of the oil content of the producing sands is obtained by the ordinary methods of flowing and pumping. A larger percentage is now recovered in some fields through

improved production methods such as compressed air or gas lifts, back pressure on flush production and flowing wells, water flooding the oil sands through key wells and pressure restoration by forcing air or gas into these sands.

The United States has produced over 10,340,000,000 barrels of oil or 65% of the world's output. It has been the largest producer except in 1898-1901 when Russia was first and this country second. Our output has increased from 190,000 barrels a day in 1901 to 2,460,000 barrels daily in 1927 and from 41.4% to 71.8% of the world's production. Conversely, the output of Russia has decreased from 233,000 barrels daily in 1901 to 198,000 barrels a day in 1927 and from 50.9% to 5.8% of the world's production.

Crude oil was first utilized for lighting and its then principal refined product, kerosene, rapidly replaced other illuminants. Gasoline, fuel oil and lubricants were relatively unimportant and largely waste by-products. The disposal of gasoline as sewage into the streams on which the refineries were built comprised the first important waste of petroleum. This has since been corrected through the utilization of gasoline in internal combustion engines and its use for other purposes.

This kerosene era continued until 1909 when refineries averaged 111,000 barrels of gas and fuel oil daily, compared to 109,300 barrels of kerosene, 35,200 barrels of gasoline and 35,000 barrels of lubricating oils a day. In 1927, our refineries produced 1,074,000 barrels of gas and fuel oil daily, 905,900 barrels of gasoline, 153,700 barrels of kerosene and 86,900 barrels of lubricants a day.

However, the value of kerosene at refineries in 1909 was $94,547,010 compared to a total of $115,119,078 for these other refined products. This dominant value position of kerosene continued until 1914 when gasoline advanced to the first position with a value of $121,919,307 as against

$96,806,452 for kerosene, $84,017,916 for gas and fuel oil and $55,812,452 for lubricants. The years 1909-1927 comprised the gas and fuel oil period of the oil industry in volume and 1914-1927, the gasoline era in value. In 1914, the conservation period began. We are now entering into an age in which gasoline will be the foremost product of refineries both in value and volume and the conservation of crude oil a more important factor.

Notwithstanding increases to 2,460,000 barrels daily in 1927 from an average of 6 barrels a day in 1859 and from 728,000 barrels daily in 1914, our petroleum production would not have been sufficient in recent years to supply one-half of the gasoline demand, under former refining methods. This gasoline requirement had increased by 885% in 1927 over that of 1914 while the crude oil production increased by only 238%.

In 1914, refineries recovered only 17.1% of gasoline from the crude oil. That recovery would have yielded only 421,000 barrels of gasoline in 1927 to supply our daily consumption and exports of 938,000 barrels. In order to meet this demand at the 1914 ratio of the refinery recovery of gasoline from crude oil, 5,485,000 barrels of crude petroleum would have had to be refined each day or 2 1/5 times our entire production and 1 3/5 times the output of the entire world.

Four important forward steps in the conservation of crude oil and in gasoline production have been developed since 1914—improved refinery apparatus and efficiency, reduction of evaporation losses, natural or casinghead gasoline plants and the cracking processes. Each of them has contributed to the supply of gasoline and its low prices and to the conservation of petroleum.

Improved refinery efficiency and decreased evaporation losses increased the gasoline yield from 17.1% in 1914 to

23.8% of the crude oil processed in 1927. This increase of 39.2% provided an additional 152,000 barrels of gasoline a day and conserved 889,000 barrels of crude oil daily, based on the 1914 gasoline recovery from crude oil. The actual conservation was somewhat more as most of the low gasoline content crudes, which were formerly used as fuel oil without being refined, are now processed and the gasoline recovered at the refineries. Natural gasoline plants produced 107,100 barrels of gasoline daily in 1927 compared to 2,782 barrels a day in 1914, an increase of 3,750%. Their conservation of petroleum amounted to 626,000 barrels a day.

Cracking plants averaged 277,300 barrels of gasoline daily in 1927, compared to 5,600 barrels a day in 1914, an increase of 4,852%. They alone conserved 1,622,000 barrels of crude oil daily. The total conservation in 1927 amounted to over 3,137,000 barrels daily in the United States, or nearly 700,000 barrels a day more than our production of crude oil.

Cracking is the supreme achievement of the oil industry, the epic of all industries. It converts through great heat and high pressures, the inferior products of crude oil, gas and fuel oil and reduced crudes, into an anti-knock gasoline which is more valuable than that produced by straight refining.

Based on the 1914 refinery recovery of gasoline from crude oil, cracking has conserved over 2,532,200,000 barrels of petroleum in the United States since 1915, increased refinery efficiency and the reduction of evaporation losses have conserved over 2,098,200,000 barrels and natural gasoline plants over 1,136,200,000 barrels. The total conservation has been over 5,766,600,000 barrels which is equal to 85.8% of the crude petroleum produced in the United States and 58.9% of the world's output since 1915. And cracking and the cracking plants have not yet been fully developed.

The history of the utilization and conservation of crude oil is that of pioneers and leaders who have made possible its present foremost position. The kerosene era was developed through the foresight and constructive ability of John D. Rockefeller and his associates, among whom were John D. Archbold, F. Q. Barstow, J. A. Bostwick, Henry M. Flagler, Alfred J. Pouch, Charles Pratt, William Rockefeller and Henry H. Rogers.

The gasoline era is the outstanding result of cooperative research and development work by the great oil companies, their officers and employees. The conservation of crude oil through cracking has depended largely upon the inventive genius of William M. Burton, Robert E. Humphreys, Edgar M. Clark, Frank B. Lewis, Thomas S. Cooke, Ralph C. Holmes, Frederick T. Manley, Joseph H. Adams, Otto Beheimer, Frank A. Howard, Carleton Ellis, Roy and Walter Cross, Charles B. Buerger, A. M. McAfee, U. S. Jenkins and others.

This gasoline or conservation era was developed through the leadership and executive ability of Robert W. Stewart, E. G. Seubert, E. C. Lufkin, Amos L. Beaty, Ralph C. Holmes, A. C. Bedford, Walter C. Teagle, George H. Jones, W. S. Farish, R. L. Blaffer, H. C. Weiss, Frederick Osborn, W. L. Mellon, George S. Davison, George H. Taber and others.

These men will become historical figures in the real conservation of crude oil in the United States. Their epic performances will be inspirational for the coming generations in our further industrial development. Were it not for them, the production ratios of gasoline in this country and Russia might have been reversed and the history of the world widely different during recent years.

INDEX

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